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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA PROGRAM APOLLO WORKING PAPER NO. 1344

APOLLO PAD ABORT LAND IMPACT TESTS
AT KENNEDY SPACE CENTER

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS
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SUMMARY

Present concepts rule that all Apollo flights terminate with landing on water. However, land landing is a possibility if Apollo flights from Kennedy Space Center Launch Complex 39 are aborted within 40 seconds of launch.

A drop-test program was initiated to define the severity of command module landings within the potential land-landing area. A portable drop-test rig was designed and a full-scale, rigid model of the Apollo command module was instrumented to provide center-of-gravity impact acceleration data. A field survey was undertaken to identify soil and vegetation types within the abort area, and representative sites were chosen for the tests. Impact conditions were selected to subject the test vehicle to the most severe landings possible. Pertinent test data in unfiltered form are presented in this report with descriptions of test apparatus, test sites, and test operations. A preliminary evaluation of the acceleration data indicates that peak impact accelerations encountered in the tests were within human-tolerance levels. Many of the unfiltered data, however, are difficult to interpret and require reevaluation using discriminative filtering techniques.

INTRODUCTION

Present mission rules dictate that all Apollo flights are to be terminated with water landing. However, if Apollo flights originating from Kennedy Space Center (KSC) Launch Complex 39 are aborted within 40 seconds of launch, the defined impact footprints include some land. In the event of an onpad abort, the probability of landing on land can be as high as 83 percent. Consequently, an impact test program was planned to established the severity of command module landing on the terrain within the abort footprints. The program objectives were accomplished by a limited number of drop tests at KSC on representative terrain using a full-scale model of the Apollo command module. Included in the program was a

drop test on the fill material of Pad 39B to verify that the sand test bed at the Manned Spacecraft Center (MSC) was an accurate simulation of Pad 39B soil, the hardest landing surface expected. The test data could then be compared to drop-test data obtained on the MSC sand test bed using the same test vehicle, a similar vehicle, and an actual Apollo spacecraft. The program also provided additional data for terrain improvement at KSC to insure a safe landing after a pad abort.

A field survey of the soil and vegetation regimes around Launch Complex 39 was undertaken to define the types of terrain to be included in the test program. Six types of terrain were classified and mapped, and five representative sites were selected for impact tests.

The test vehicle used was a full-scale, rigid-model boilerplate (BP) representative of the Apollo command module. The test vehicle was instrumented to obtain time-history data on pertinent parameters which describe the dynamic behavior of the vehicle center of gravity.

A portable, drop-test rig was designed specifically for the test program. The rig, of four-bar pendulum design, was mounted on a flatbed truck and supported by six guy cables. The rig could be moved without disassembly by releasing the cables, supporting the rig by a crane, and "walking" the truck and crane to a new site.

Certain initial impact conditions were established for the entire test series. A vertical impact velocity of 38 fps was specified to simulate a two-parachute landing. The 37-fps maximum horizontal velocity attainable with the portable test rig was applied in all tests. Test vehicle attitudes were varied to simulate different types of severe landings. A 0° roll was specified to maximize crew accelerations, and 180° roll was specified for maximum structural damage due to tumbling. Three tests were made for each type of terrain, two at 0° roll and one at 180° roll.

Pertinent test data in unfiltered form are presented in this report along with a description of test apparatus, test sites, and operation of the tests.

TEST APPARATUS

Test Vehicle

The vehicle used in the drop-test series was a full-scale boilerplate (BP-25) representation of an Apollo command module.

The BP vehicle was constructed as structurally rigid as possible in order to minimize damage requiring refurbishment after each test. Comparision of impact accelerations experienced by rigid models and those experienced by actual spacecraft has indicated that structural failure in the spacecraft results in lower accelerations at the crew couch. Hence, impact data obtained using a rigid model are usually conservative.

Steel I-beam supports were used with 3/16-inch steel sheet for exterior facing. The sidewalls were supported by I-beam stringers and the heat shield by a wagon-wheel arrangement of I-beams in the floor. No attempt was made to model the crew couch or crew cabin. The BP weight, inertias, and center-of-gravity location were modeled to current spacecraft specifications by adjusting lead disks mounted on four posts welded to the floor and top deck. The significant specifications of the test vehicle are listed below.

Specification	Value
Weight (without instrumentation), lb	12 720
Center-of-gravity (by vehicle coordinate system) location, in. . . .	$x = 38.5$ $y = -0.02$ $z = 4.6$
Inertia, slug-ft^2	$I_{xx} = 5650$ (calculated) $I_{yy} = 5097$ (measured) $I_{zz} = 4420$ (calculated)

Test Rig

The rig chosen to provide the necessary vertical and horizontal vehicle velocities was a four-bar pendulum swing rig (fig. 1). In a swing rig, the vehicle hangs from a platform at the lower end of the pendulum. The vehicle is positioned at the roll, pitch, and yaw attitudes desired at impact. The pendulum arm is then pulled back and released, and the spacecraft is disconnected from the platform as the pendulum swings through dead center. The vertical velocity at impact is controlled by the vertical distance between the vehicle at release and the impact point (the free-fall distance). The horizontal velocity is controlled by the amount the pendulum is pulled back initially.

Portability was a necessary feature of the swing rig to permit movement to a variety of test sites. The rig was designed to be supported by guy cables and to be easily dismantled for movement. Three test drops were planned for each selected test site with impact centers to be separated by 20 feet. Therefore, a guying system was developed to allow the rig to be moved 20 feet to either side of a symmetrical central setup without changing guy anchors. All three drops could then be made with one setup. Cable lengths and tensions were precalculated for each of the three positions composing a series. The anchor points for the guy cables were provided by screw anchors 5.5 feet long with an eye on one end and a spiraled plate on the other. The plate end was screwed into the ground until only the eye showed. At each new location pull tests were conducted to be sure that the soil would enable the screw anchors to hold the required loads.

The entire swing rig rested on a lowboy truck bed. After a drop was made at one position, the weight of the rig was partially supported by a crane, and the guy cables were adjusted as necessary as the truck bed was pulled 20 feet to set up the next test. Final alinement of the rig was obtained by fine adjustments of the guy cables and fine leveling of the rig base with surveying equipment.

The vertical support for the pendulum pivot was supplied by two 72-foot upright columns. The platform suspending the pendulum was fastened to the top of the uprights. Two braces, forming a triangle with each upright, provided at their junction the proper point from which to retract the pendulum. The pendulum was of a four-bar design with a suspension platform which would hold the drop vehicle at specified attitudes. Two pyrotechnic releases were installed on the swing rig. One released the retracted pendulum, and the other disconnected the boilerplate from the pendulum platform at bottom dead center of the swing.

The release devices (fig. 2) were of a type often employed on parachute drop tests to disconnect parachutes at vehicle impact. The devices consisted of an arm pivoted at one end and capable of being pyrotechnically released at the other end. When released, the arm pivoted and freed whatever was connected to it. The release for the swing of the pendulum was controlled from the ground. Release of the test vehicle from the pendulum was activated by striker arms mounted on the forward pendulum legs. As the pendulum swung through center, displacement of the striker arms by the upright columns activated microswitches for the release pyrotechnics. Flashbulbs in the release circuits gave visual evidence of release firings for photographic coverage. Circuit diagrams of the release systems are described in figure 3.

Test Instrumentation

Measurement data.- A purpose of the tests was to gather information on the dynamic behavior of the test vehicle when subjected to landings under the same conditions of attitude and velocity but on different terrains. Measured parameters were limited to linear acceleration in all three axes, angular acceleration in pitch α_y, and angular velocities, all about the center of gravity of the vehicle. The angular velocity and angular acceleration measurements were taken primarily to insure that initial impact conditions were correct since the transducers available did not have the frequency response to measure the high angular rates generated by impact. To provide redundancy, X and Z linear accelerations were also monitored at another location in the test vehicle.

Nine transducers were used to gather impact data. A triaxial accelerometer, a triaxial rate gyro, and an angular accelerometer were clustered at the c.g., and a biaxial accelerometer was placed 1 foot from the c.g. (remote location on table I) on the minus Z-axis. The transducers were mounted on a wooden beam (fig. 4) clamped to the weight posts.

A self-contained, onboard telemetry system transmitted the data signals to ground station receivers. The telemetry package was mounted on an aluminum pallet bolted to aft heat shield bulkheads. The transmitter battery package was mounted separately on the Z-axis against the sidewall. To minimize damage, battery-mounting brackets were adjusted so that impact loads were transmitted to the battery cells along their longitudinal axes. Signal loss due to vehicle interference was prevented by using two antennas for data transmission. The antennas were mounted on the top deck on the Z-axis, one on either side of the docking tunnel. To simplify field testing, a shorting plug, ON-OFF, and calibration switches were also mounted on the top deck. The locations of instrumentation components are shown in figure 5.

A 247.3-mHz, 6.0-watt, standard inter-range instrumentation group (IRIG) proportional bandwidth telemetry package was used. A list of transducers with corresponding IRIG channel allocation is given in table I.

Telemetry data were received and recorded as multiplexed signals on frequency modulation (FM) tape. Receiving and recording equipment was located in a van parked in close proximity to the test rig. Tests 1 through 7 were also recorded at the permanent ground station (CIF) at Kennedy Space Center, approximately 6.5 miles from the test area. Tests 8 through 13 were recorded at the Air Force radar station (TEL-IV), approximately 11 miles from the test area. As KSC had no instrumentation vans available at that time, the TEL-IV ground station was the only receiving station used on drops 11 through 13. The FM/FM data tapes were

shipped to MSC where they were demultiplexed and the unfiltered data put on strip charts for evaluation.

Photography.- Still photographs in color were taken of each impact area immediately before each test to show the ground in the undisturbed state. After each boilerplate impact, the areas were photographed again both before and after removal of the boilerplate from the impact depression. Disturbances caused by impact were clearly shown.

In addition to still photographic coverage, the tests were recorded in color by motion picture cameras. The motion cameras were equipped to apply 0.01-second timing indications to the film. Time-indicated film is useful in understanding physical situations related to measured data. Velocities, both horizontal and vertical, can also be approximated from good film coverage if a length reference is visible in the field of view. The length reference was a large background board painted in a checkerboard pattern of 12-inch squares. The board measured 8 feet high by 20 feet long and was placed just to the side of the drop area for each test.

Three or four motion picture cameras were used, depending on individual test conditions. One camera operating at 400 frames per second was alined to record the release of the boilerplate from the suspension platform. The purpose was to give visual evidence of any attitude rates initiated at release. A second camera, also at 400 frames per second, was centered on the grid pattern board to show the final several feet of boilerplate fall and impact. When, because of certain test conditions, a large amount of boilerplate travel after impact was expected, another 400-frames-per-second camera was used to cover the area into which the boilerplate was expected to travel beyond the field of the gridboard camera. In addition, another camera operating at 48 frames per second was used to track the boilerplate throughout the drop.

TEST SITES

A field survey (Soil Survey of John F. Kennedy Space Center in Support of CM Land Impact Program by E. F. Nordmeyer, and Richard A. Werner, Manned Spacecraft Center, January 15, 1968) of the soil and vegetation regimes around Pads 39A and 39B at KSC was conducted during October and November 1967. The survey included mapping and studying the salient physical properties at the various regimes. The type and extent of the

main soil and vegetation regimes within a 2-mile radius of Pads 39A and 39B are listed below.

Area type	Inland coverage, percent
Palmetto	26
Water	24
Grass	18
Organic muck	13
Fill material	12
Beach and dunes	7

The 2-mile radius included the 95-percent impact area footprint in the +40-second abort situation. From the six major regimes, 36 individual sites were investigated in detail. Then one drop site was chosen in each of the soil and vegetation regimes except the beach and dunes regime. Figure 6 shows the location of each of the drop sites. The beach and dunes regime, which comprised only 7 percent of the inland area of interest, was omitted for several reasons. The surfaces were not level in any of the areas where the test rig could be used. Since tests on other regimes were to be done on level surfaces, the data would not be comparable. To level a drop area in the regime would change the natural characteristics. Also, it was felt that the fill material drop site near Pad 39B would also give some representation of the beach and dunes area since both are sand or shell materials.

For a complete discussion of the regimes, soil types, and soil physical property curves, the referenced document should be consulted. A very general description of the five most prevalent regimes and the drop sites selected follows.

Fill Material Area

Twelve percent of the inland area of interest is made up of a hydraulically dredged fill material which ranges from sand to very shelly material. The fill has been used to construct both pads and both crawlerways and has been highly compacted to reduce settlement. Where there is vegetation, it is in the form of grass, similar to a well-kept lawn.

The drop site was located in the southwest quadrant of Pad 39B which was the only area available during the Apollo-Saturn 501 (AS-501) prelaunch period. The soil physical property curves indicate that the fill area drop site was representative of the entire fill area. Figure 7 shows the drop site.

Palmetto Area

Palmetto covers 26 percent of the area of interest which is the largest percent of coverage of any of the six soil and vegetation regimes. Palmetto soils have low to very low available water capacity, low natural fertility, and very rapid to rapid permeability.

Vegetative conditions in the palmetto area were divided into dense, moderate, and thin categories of palmetto coverage. The dense and moderate categories were typified by larger, taller fronds and larger trunks than the thin palmetto coverage areas, but comprised only a small portion of the total palmetto area. The thin palmetto was typified by a frond height of 2 to 3 feet and by a frond width of 12 to 18 inches. The fronds stemmed at ground level from trunks which were 4 to 6 inches in diameter. The trunks, which were partially buried in the ground, were about 30 inches apart and rarely overlapped. Small brush and weeds 1 to 3 feet high were usually scattered throughout this type of palmetto.

The moderate-type palmetto was typified by a frond height of 3 to 5 feet and a frond width of about 24 inches. The fronds stemmed from the trunk approximately 6 inches above the ground. The trunks were 6 to 8 inches in diameter and were on or partially buried in the ground. The trunks were spaced an average of roughly 20 inches apart. In the moderate palmetto areas there were usually no brush or other plants.

The thick, dense palmetto coverage was typified by a frond height of 6 to 8 feet and a frond width of about 30 inches. The decumbent trunks of the palmetto were 8 to 10 inches in diameter and lay on the ground in a coarse interwoven mat. In general, dense palmetto is associated with an abundance of brush sometimes reaching as high as 18 to 24 feet.

The drop site in the palmetto area was selected because it was representative of the majority of the palmetto soil and vegetation regime. The drop site was composed of both the moderate and the thin palmetto coverage. The site was chosen so that the boilerplate would impact into the moderate palmetto and, if sliding, rolling, or tumbling occurred, it would move into an area of thin palmetto. The site is shown in figure 8.

Grass Area

The grass area, covering 18 percent of the total inland area of interest, was composed of two major types of grasses, sand cordgrass and seashore saltgrass.

The sand cordgrass grew from 3 to 5 feet tall and in stem clusters 2 to 3 feet in diameter. The clusters averaged 6 to 8 inches apart with the spaces usually clear. The leaf width of this grass was about one-fourth inch. Cordgrass grew in areas which were not excessively drained and which contained some water salinity. The grass can withstand water table fluctuations from a depth of approximately 2.5 feet to approximately 2 to 3 inches above ground.

Seashore saltgrass was a short grass growing to a maximum height of 6 inches and in a very dense mat. It grew in areas having a high water table (from 6 inches below to 2 inches above ground) and some water salinity. Of the total grass area, seashore saltgrass covered only a small portion.

The grass drop site was chosen adjacent to the palmetto drop site to minimize movement of the drop rig between areas. The salient characteristics of the majority of the grass areas were represented here. The drop site was covered with sand cordgrass, 3 feet tall over the entire impact zone. The site is shown in figure 9.

Organic Muck Area

Organic muck comprised approximately 13 percent of the inland area of interest about Pads 39A and 39B. Considerable fluctuation of the water table was observed in muck areas depending on the amount of rainfall. Some of the areas remain covered with 6 to 12 inches of water even from November to May, the dry season. In other muck areas, the water table during the dry season fell to a depth of 6 to 12 inches below the surface. The organic muck did not exhibit a high-bearing capacity. There was no vegetation growing in the muck soil regime. However, some very brittle dead mangrove trees were found in a few places.

A drop site just north of Pad 39B just off Florida highway 401 was selected originally. The site had to be relocated later due to fluctuation of the water table. An area at the tip of a slough off Banana Creek was then chosen as being fairly representative of the organic muck areas. The slough tip was blocked off from the main body of water with an earthen dam so that the water depth in the tip could be controlled by pumping. The slough tip was pumped down to 4 to 6 inches of water depth for the organic muck tests and later pumped back up to 30 to 36 inches for the shallow water tests. The organic muck site is shown in figure 10.

Water Area

About 24 percent of the inland area of interest is covered with water. Most of the water is shallow and can be characterized as being 24 inches deep with very small areas up to 36 inches deep. The originally chosen drop site for shallow water was later moved about 100 feet to correspond with the area mentioned above in which the water level could be controlled. The water level was adjusted to 30 to 36 inches for the tests. Figure 11 shows the drop site flooded with water.

TESTS

Procedure

The first steps in the conduct of a typical impact test included erection, positioning, and alinement of the swing rig. Prior to the arrival of the rig in a new location, surveyors had laid out the three drop centers in a line with proper spacing. They had also marked the locations for the various guy line anchor points from layout drawings.

After the screw anchors were set, the rig was brought in and erected as closely as possible to the correct position for the first drop. The surveyors aided in final positioning and alinement of the rig so that the pendulum swing was centered through the rig and was perpendicular to the line of drop centers. Fine adjustments were made with the various guy lines to obtain the proper positioning and alinement of different parts of the rig. The fine adjustment was done on the morning of the test so that settling and shifting would have less time to cause changes.

The gridboard for the photographic background was then placed and made level at the desired location to provide proper reference for the photographic coverage from the last few feet of fall until just after impact. As the photographic gridboards were placed, the ordnance personnel readied the pyrotechnic release system for attachment of the test vehicle. The motion picture cameras and data receiving equipment with associated timing devices were also made ready at the same time.

The test vehicle was then suspended from the pendulum platform at the desired impact roll and pitch angles. As the vehicle was suspended, still photographs were taken of the immediate impact area to document the appearance before it was disturbed. After the test vehicle was in position, ordnance personnel completed the pyrotechnic arming of the release system. A manual pretest calibration of the instrumentation was next conducted, after which the area was cleared for the drop. Finally the pendulum was pulled back and released, throwing the test vehicle into the impact area.

Post-test calibrations were manually conducted as soon after impact as possible so that instrumentation and receiving equipment could be turned off. Still photographs showing the test vehicle in the final position were taken before it was moved to expose the impact depression. Before the vehicle was moved, an inclinometer was used to measure the pitch and yaw angles at the final rest position. After carefully lifting the vehicle, the impact depression was measured for length, width, depth, and distance between the first indication of impact and a standard point on the rig structure. Still photographs were also taken of the impact depression with a ruler or other ordinary object for size reference.

The concluding field measurements taken were of soil-bearing capacity near the impact point. The bearing capacity was measured in an undisturbed portion of the terrain usually 5 to 10 feet from the edge of the disturbed impact area. A bearing plate of known size was placed on the lower end of a hydraulic jack and forced into the ground as the jack was extended. The jack ram was kept from rising by a large dead weight (in this case, part of a large bulldozer) upon which the ram pushed. As the ram was extended, the distance that the bearing plate traveled into the ground was recorded along with corresponding force readings from the hydraulic jack gage. The soil penetration depth was recorded every 500 pounds until either the jack force reached 10 000 pounds or the penetration depth reached 30 inches. After each drop, bearing measurements were taken with two bearing plates, one 4 inches and one 8 inches in diameter. Bearing tests were not conducted at either the shallow water or organic muck sites because of inaccessibility due to the water cover.

Impact Conditions

Three basic landings were simulated on each terrain type with the exception of the first site. The hard-packed sand test area had been simulated at the impact facility at MSC and impact data were already available. Only one test was made on KSC Pad 39B hard-packed sand to verify similarity with the test bed at MSC. One of the most severe landing attitudes for the Apollo command module with respect to crew accelerations occurs at 0° roll, 0° yaw, and 27.5° pitch. This landing attitude was made on all five types of terrain. The second case chosen was the most severe from the standpoint of vehicle structural damage. At 180° roll, 0° yaw, and 27.5° pitch, the vehicle will tumble end over end at impact. The third test was made at attitudes of 0° roll, 0° yaw, and 36° pitch. The test was the same as the first except for the greater pitch angle. It was expected that the increased pitch angle would allow the vehicle to pass through the surface vegetation more easily, resulting in more severe impact accelerations.

The test rig was designed so that no angular rates were induced in the test vehicle and the test vehicle could be mounted on the rig at the impact attitude chosen for that particular test. The rig pendulum arms were adjustable to allow two vertical impact velocities. Except for the test on Pad 39B, all tests were made at the higher velocity, approximately 38.0 fps, or the impact velocity encountered with a two-parachute landing. The horizontal velocity selected was the highest velocity attainable with the portable rig, approximately 37.0 fps. According to statistical data available for Cape Kennedy, the wind velocity is below 37.0 fps 95 percent of the time.

Initial pitch attitude and velocities were checked and verified for each test. Pitch attitude was verified using film from the engineering sequential cameras. The vehicle attitude at release and at impact was measured visually to verify the pitch angle and the absence of angular rotation. Actual vertical impact velocity was calculated by two different methods. As the distance from the top of the test rig outriggers to the ground level was measured at each test site, the vertical free-fall distance was known, and hence the vertical velocity could be calculated. In addition, the vertical velocity could be calculated using the free-fall time obtained from the accelerometer data. By averaging the results of the two calculations, the vertical velocity could be determined with an accuracy of ±0.5 fps. Horizontal impact velocity was difficult to determine with precision although three separate methods were used. All 14 drop tests were made using the full capability of the test rig to obtain the highest horizontal velocity. The most accurate calculation method used the horizontal distance traveled and the free-fall time to solve for horizontal velocity. The gridboard was placed a known distance from the test rig uprights. The vehicle released position and the film from the engineering sequential camera, giving gridboard coverage, were used to determine the total horizontal distance traveled by the vehicle. The free-fall time was taken from accelerometer data. This method gave an accuracy of approximately ±1.0 fps. Using only the gridboard camera film to obtain horizontal distance traveled in a given amount of time was not as exact since camera lens parallax prevented accurate measurement of distance. Another method, using only the accelerometer data, was discarded also. It used the pendulum swing time and the pendulum arm length in an elliptic integral of the first kind to determine the swing angle. When the swing angle is known, pendulum velocity at vehicle release can be found. This method should give the best results, but difficulty in precisely determining swing time from the data negated the method's usefulness.

The initial conditions for each test are shown in table II.

RESULTS AND DISCUSSION

Accelerometer data from each of the 14 tests are presented in the appendix (figs. A-1 through A-14). Data from only the three accelerometers (X, Y, and Z) mounted at the center of gravity are presented as the other instrumentation was either redundant or intended to give other than impact information. The impact data are grouped according to initial conditions. Tests 2, 5, 9, and 12 made at 0° roll, 27.5° pitch; tests 4, 7, 10, and 13 made at 0° roll, 36° pitch; and tests 3, 6, 8, and 11 made at 180° roll, 27.5° pitch are arranged in separate groups for comparative purposes. During the Pad 39B palmetto and grass tests, the data were recorded in an onsite instrumentation van as well as at the CIF building 6 miles away. Because of launch requirements, both the instrumentation van and the CIF building were unavailable during the organic muck and shallow water phases. For these tests the data were recorded at the TEL-IV communications facility 11 miles away. Noise levels on the recorded data were generally higher at the more remote recording stations. Data from the test at MSC and the Pad 39B test at KSC were for a different vertical velocity than the rest of the KSC tests. The Pad 39B test was conducted for direct comparison with other work being done at MSC.

Since all of the landing tests were symmetrical with respect to the Y-axis of the vehicle, the measured Y acceleration at the vehicle center of gravity during impact should have been negligible for all tests. Hence, any variation in acceleration shown in the data is an indication of the noise present on the accelerometer traces for that particular test.

The MSC test and the KSC Pad 39B test (test 1) show rather close correlation with respect to peak accelerations. The test on MSC sand indicated acceleration peaks of approximately 30g and 28g in the X and Z directions, respectively, compared to 35g and 35g (X and Z directions, respectively) for the KSC test on Pad 39B.

For the 0° roll, 27.5° pitch tests (tests 2, 5, 9, and 12), the maximum acceleration of the vehicle center of gravity at impact in the X direction varied from the high of 25g on palmetto to about 8g in shallow water. The peak Z accelerations covered greater range, from 28g on palmetto to about 5g on organic muck and shallow water. The large range of Z accelerations is explained by the differences in surface resistance of the palmetto area and that of water.

The peak X accelerations for tests made at 0° roll and 36° pitch (tests 4, 7, 10, and 13) varied from 23g on grass to 5g on shallow water organic muck. The peak Z accelerations varied from approximately 30g on palmetto to about 3g on shallow water.

The 180° roll, 27.5° pitch drop tests (tests 3, 6, 8, and 11) resulted in vehicle tumbling on grass and palmetto but not on the organic muck and in shallow water. The latter two did not result in vehicle tumbling, as the low-surface resistance of swampy soil and water allowed the vehicle energy to be attenuated in "slide out" rather than rotation. The peak acceleration in the X direction occurred at first impact in all cases and varied from a high of approximately 40g on palmetto to a low of 18g in shallow water The acceleration in the Z direction varied from 12g on grass to 6g in shallow water.

A tabulation of the peak accelerations in X and Z for all tests is included in table II.

CONCLUSIONS

The palmetto drop made at 180° roll, 27.5° pitch, showed higher accelerations in X than any other test. This was probably a result of the lack of vegetation at the initial impact point. The area was covered with medium-height palmetto scrub interspersed with a thin, woody shrub. The test sites within a selected drop area were chosen randomly; consequently, it happened that there were no palmetto scrubs at that impact point.

In comparing the five tests made at 0° roll and 27.5° pitch, it was evident that each of the terrains tested had unique properties of impact attenuation and that landings made in palmetto, grass, organic muck, or shallow water resulted in lower impact accelerations than those experienced on hard-packed sand or fill material.

Comparison of the data from tests at the Manned Spacecraft Center and the one made on Pad 39B fill material indicated a close similarity in soil properties that contribute to impact attenuation. Additional data on the three-parachute landing condition have been obtained using a similar boilerplate vehicle (BP-1201) on the Manned Spacecraft Center sand. As BP-1201 has also been tested for a two-parachute landing condition, it should be possible to relate these data to the two-parachute landing data obtained with BP-25 at Kennedy Space Center on palmetto, grass, organic muck, and shallow water. After completing a comparison of test data taken at the Manned Spacecraft Center impact facility and the Kennedy Space Center test sites, a definition of the peak, rigid-body, impact accelerations for two- or three-parachute vertical velocities, 0° roll, 27.5° pitch, on all terrain expected to be encountered should be possible.

The information obtained from the above comparison is not useful unless it can be related to an actual spacecraft. It is known that

defining spacecraft-landing capability using impact accelerations experienced by rigid spacecraft models is usually conservative. Comparing the data from the small number of spacecraft drop tests to those from similar, rigid-body drop tests indicates that spacecraft structural failure absorbs some of the impact loads, and results in lower accelerations of the crew couch.

A preliminary evaluation of the rigid-body accelerations using unfiltered data indicated that peak impact accelerations, onset rates, and durations encountered in the Kennedy Space Center test series were within human-tolerance levels. However, it must be emphasized that the physical properties encountered at the specific test sites were of a random nature, and it is certainly possible that the same vehicle subjected to similar conditions could experience higher or lower accelerations when landing on similar terrain.

TABLE I.- MEASUREMENT INSTRUMENTATION

Parameter	IRIG channel	Nominal frequency response, Hz	Full-scale reading
X rate	8	45	60 deg/sec
Z rate	9	59	120 deg/sec
Y angular acceleration	11	110	100 rad/sec
Y c.g. acceleration	12	160	50g
Y rate	13	220	360 deg/sec
Z remote acceleration[a]	14	330	100g
Z c.g. acceleration	15	450	100g
X remote acceleration[a]	16	600	100g
X c.g. acceleration	E	2100	1100g

[a]Biaxial accelerometer placed 1 foot from c.g. on minus Z-axis.

TABLE II.- TEST CONDITIONS AND IMPACT ACCELERATIONS

Test no.	Site	Roll, deg	Pitch, deg	Vertical velocity[a], fps	Horizontal velocity[b], fps	Peak acceleration at the c.g., g	
						X	Z
	MSC sand	0	27.5	34.5	38.8	30	28
1	Pad 39B	0	27.5	34.5	37.2	35	35
2	Palmetto	0	27.5	37.5	36.4	25	28
3	Palmetto	180	27.5	37.2	38.8	40	8
4	Palmetto	0	36	36.9	38.3	18	30
5	Grass	0	27.5	39.1	36.5	19	22
6	Grass	180	27.5	39.8	37.4	26	12
7	Grass	0	36	39.0	36.5	23	20
8	Organic muck	180	27.5	41.3	37.1	43	8
9	Organic muck	0	27.5	41.7	37.9	14	5
10	Organic muck	0	36	41.8	37.5	5	5
11	Shallow water	180	27.5	39.9	38.2	18	6
12	Shallow water	0	27.5	39.4	36.1	8	5
13	Shallow water	0	36	39.5	36.3	7	3

[a]Tolerance ±0.5 fps.

[b]Tolerance ±1.0 fps.

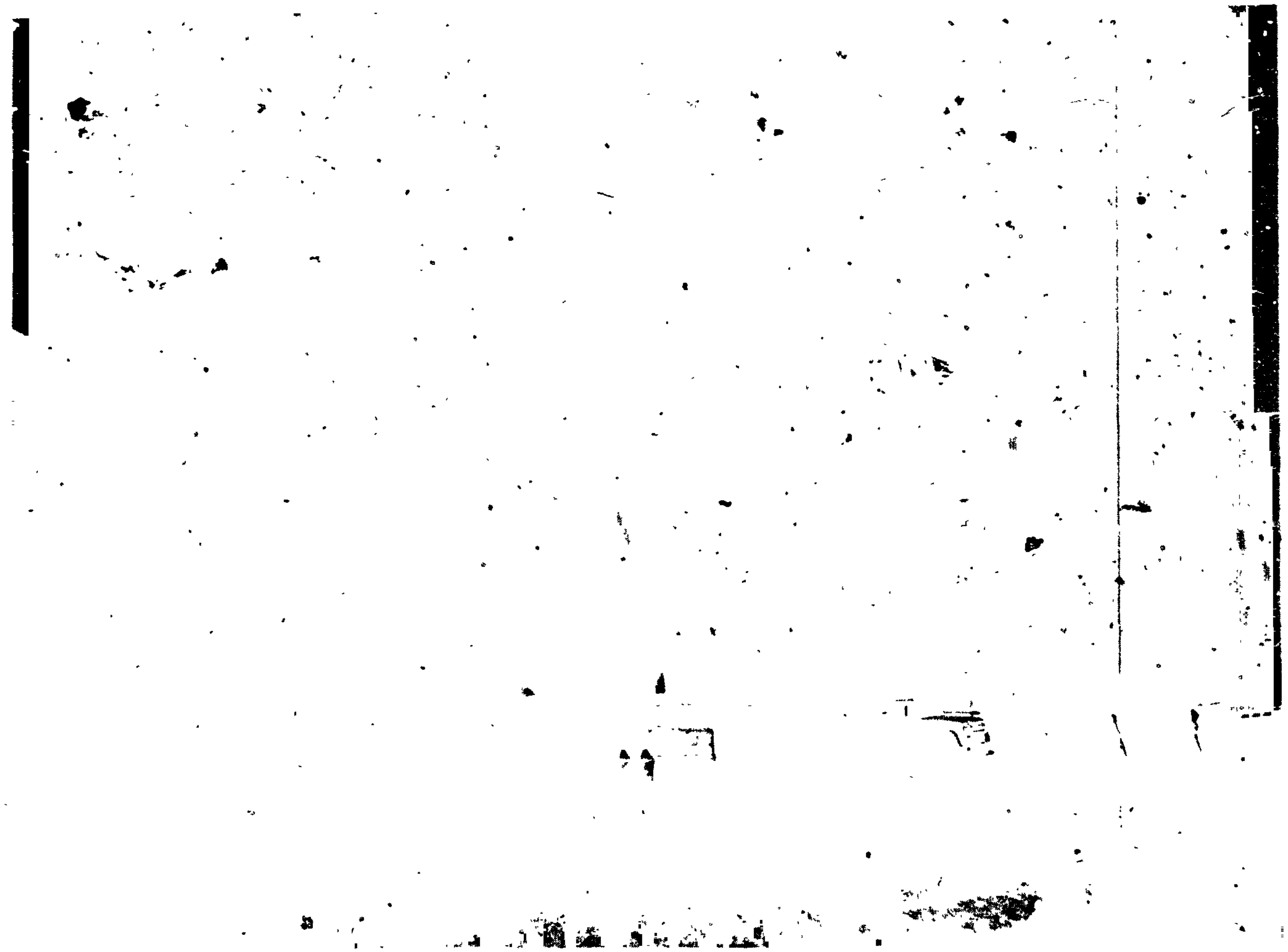


Figure 1.- Swing rig with test vehicle in partially retracted position.

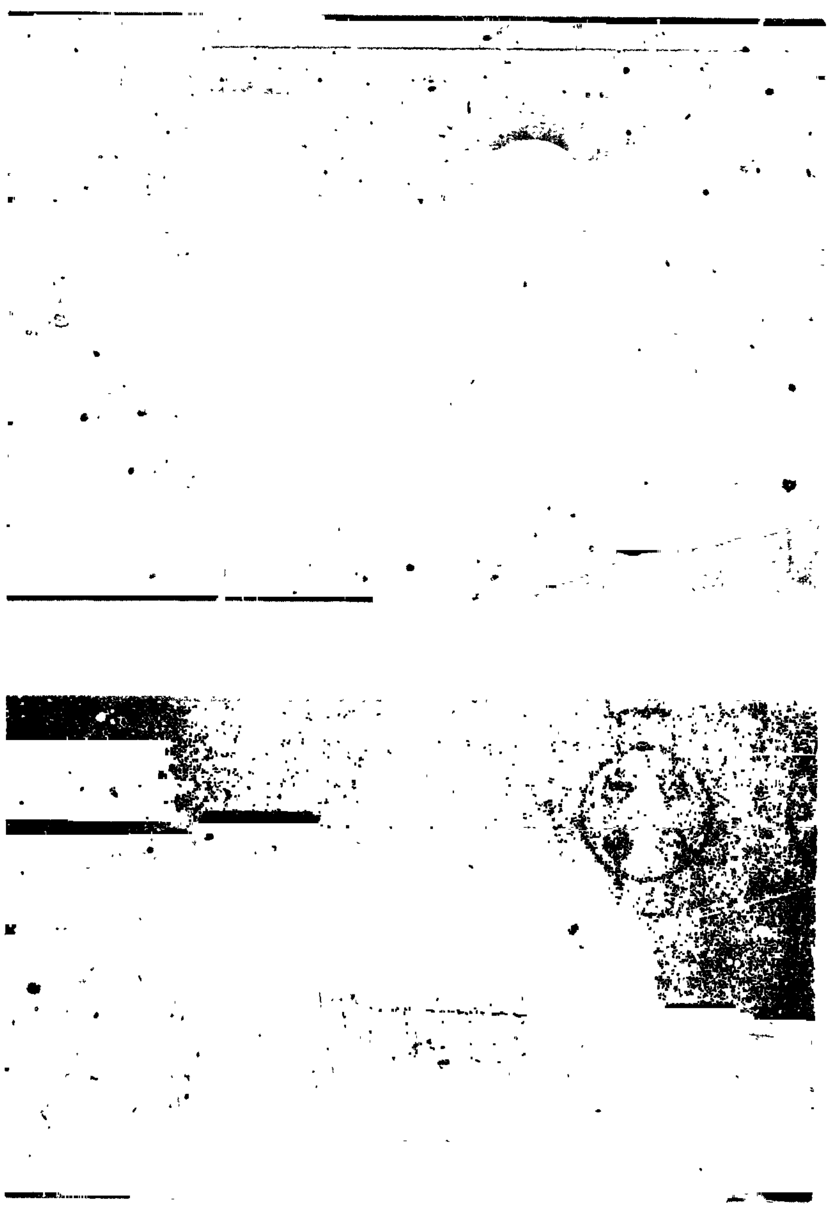
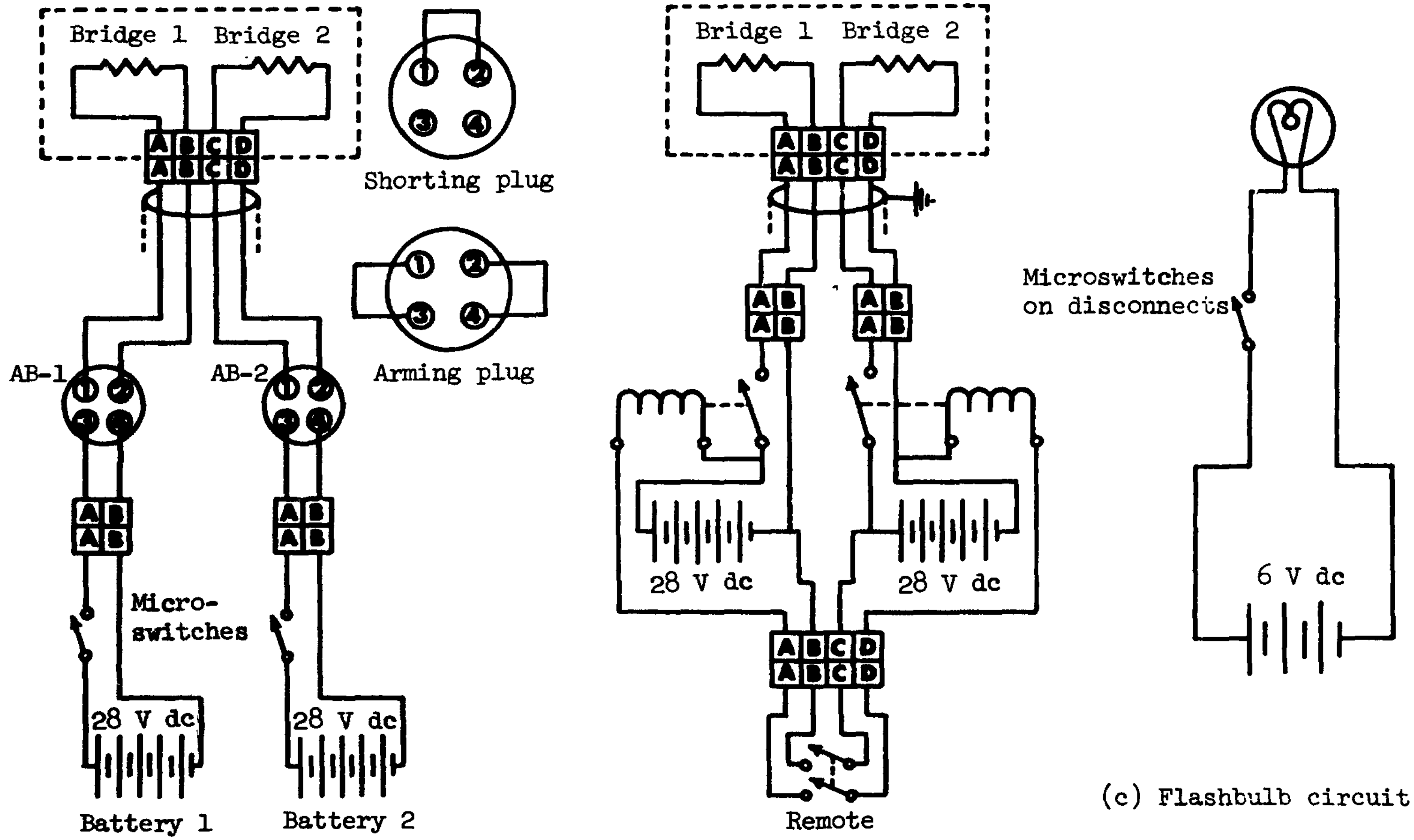


Figure 2.- Pyrotechnical release device.



(a) Test vehicle release

(b) Swing release

(c) Flashbulb circuit

Figure 3.- Pyrotechnical circuits for portable drop test rig.

Figure 4.- Transducers as mounted on wooden beam.

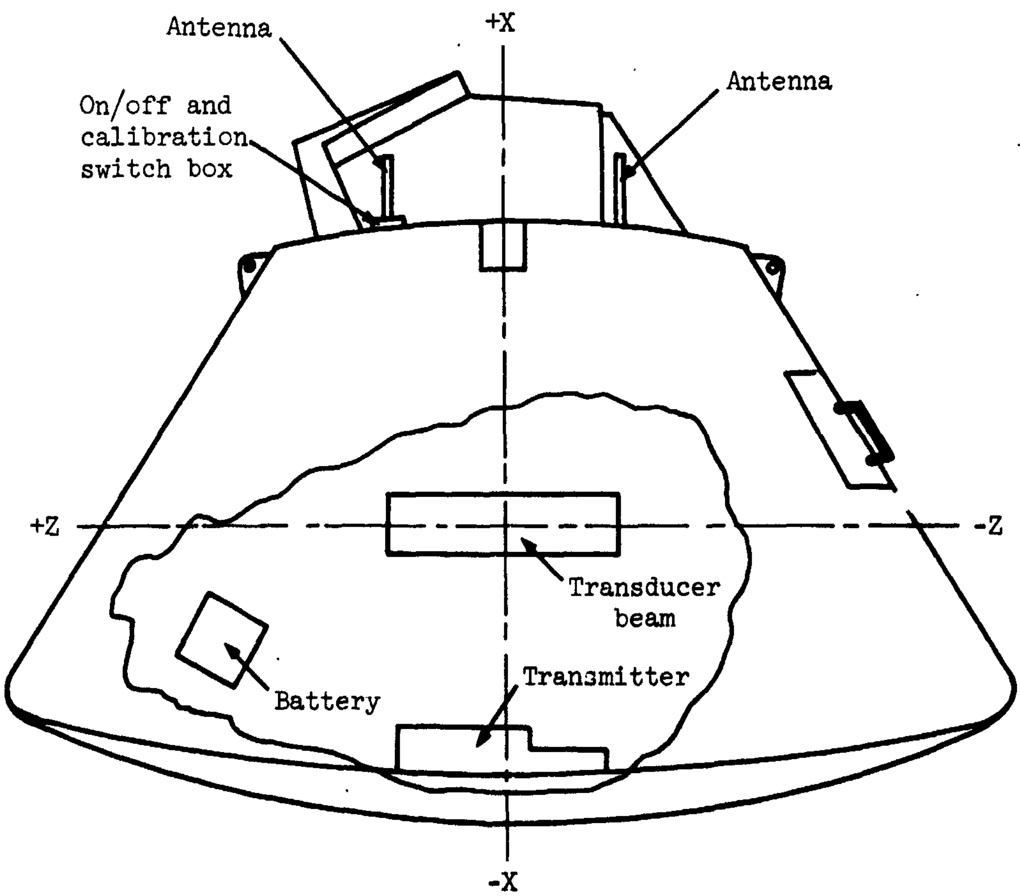


Figure 5.- Locations of instrumentation components on test vehicle.

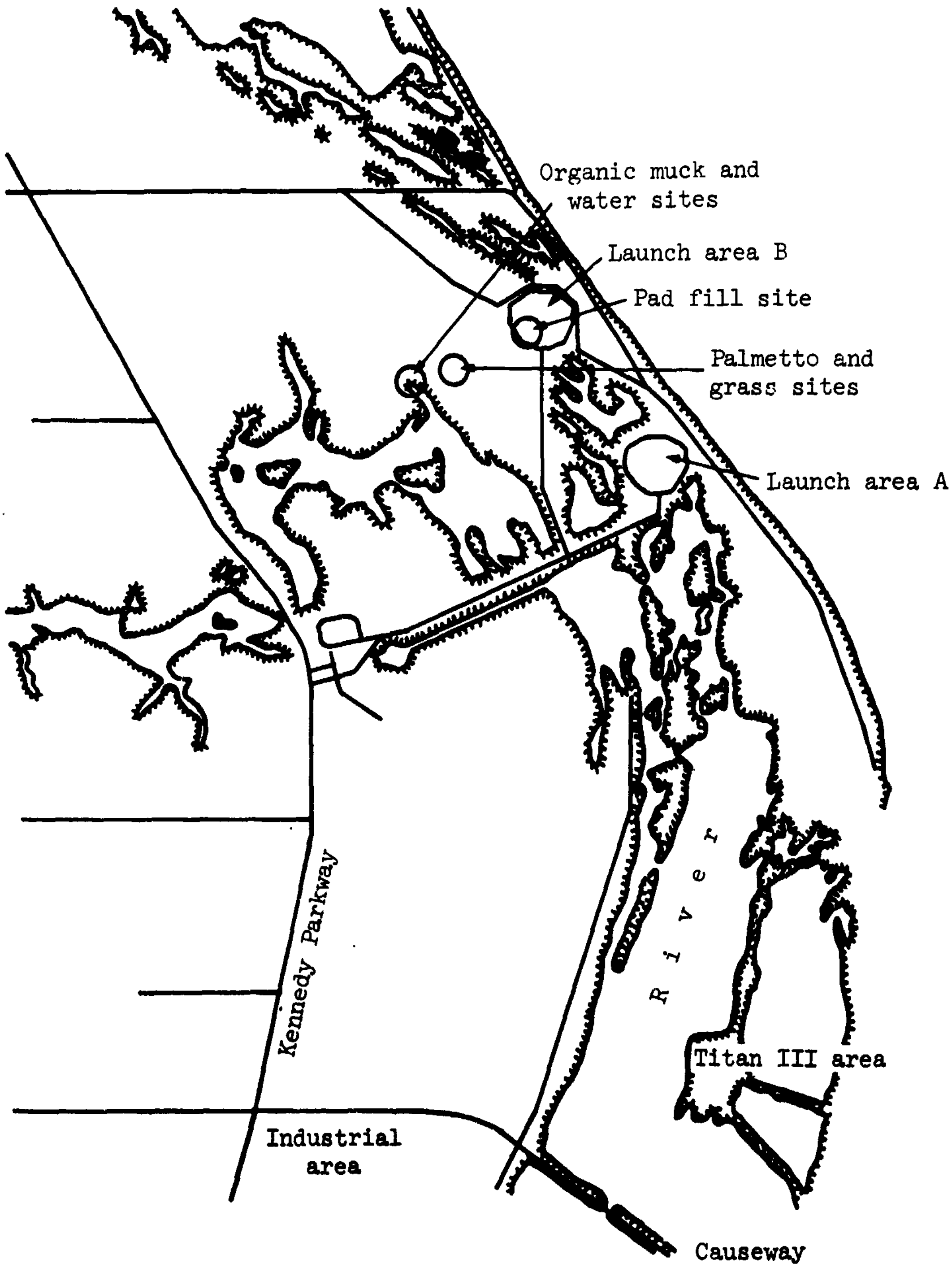


Figure 6.- Locations of drop sites at KSC Launch Complex 39.

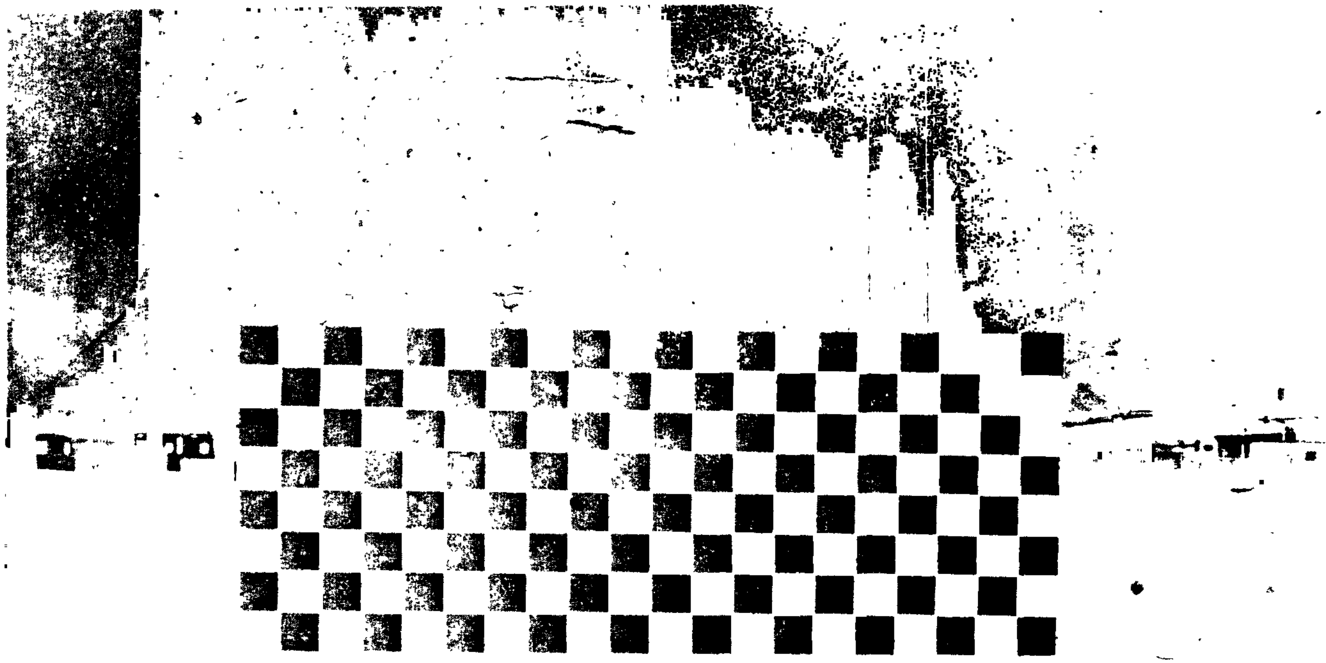


Figure 7.- Drop site in fill material.

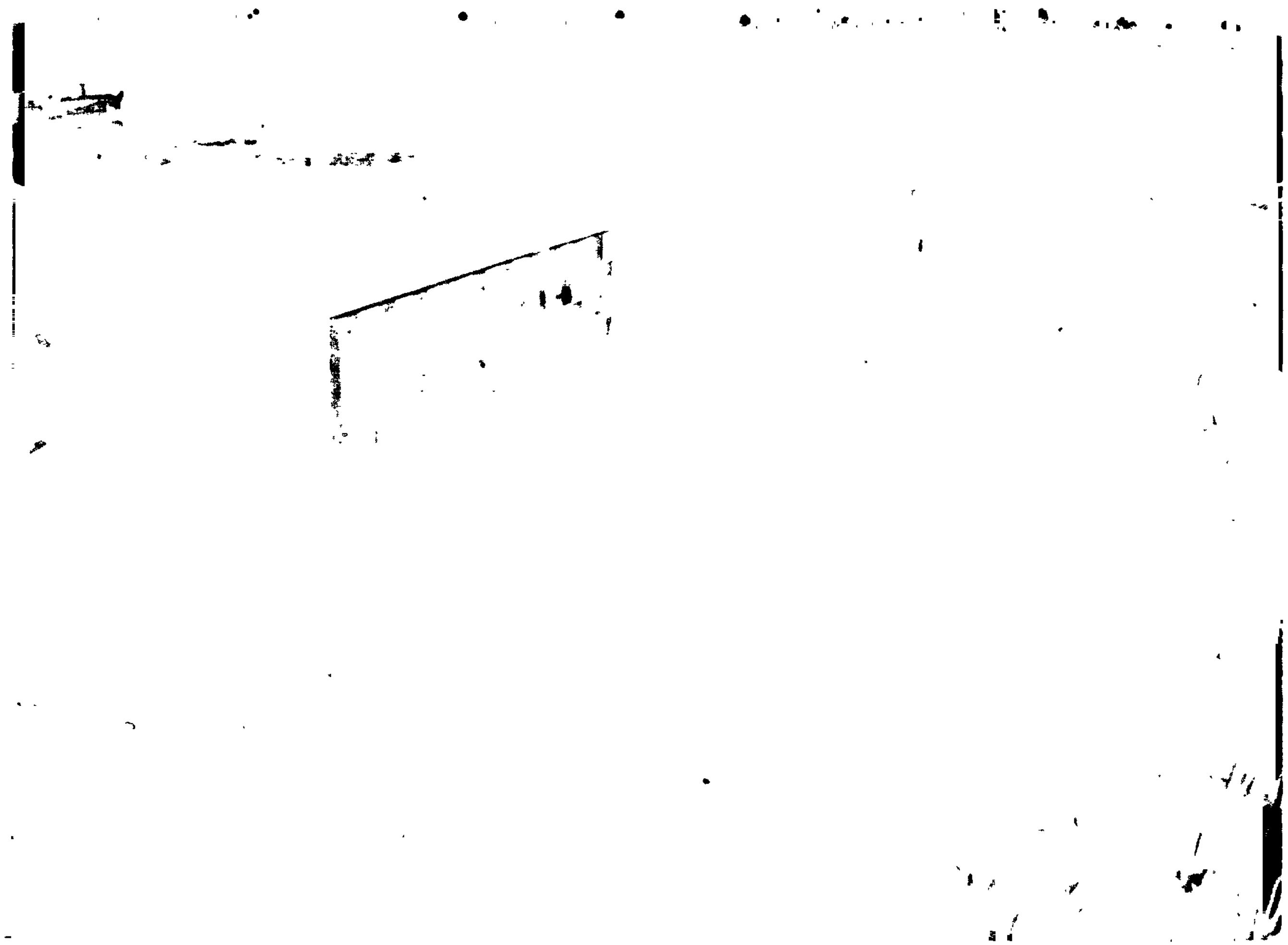


Figure 8.- Drop site in palmetto.

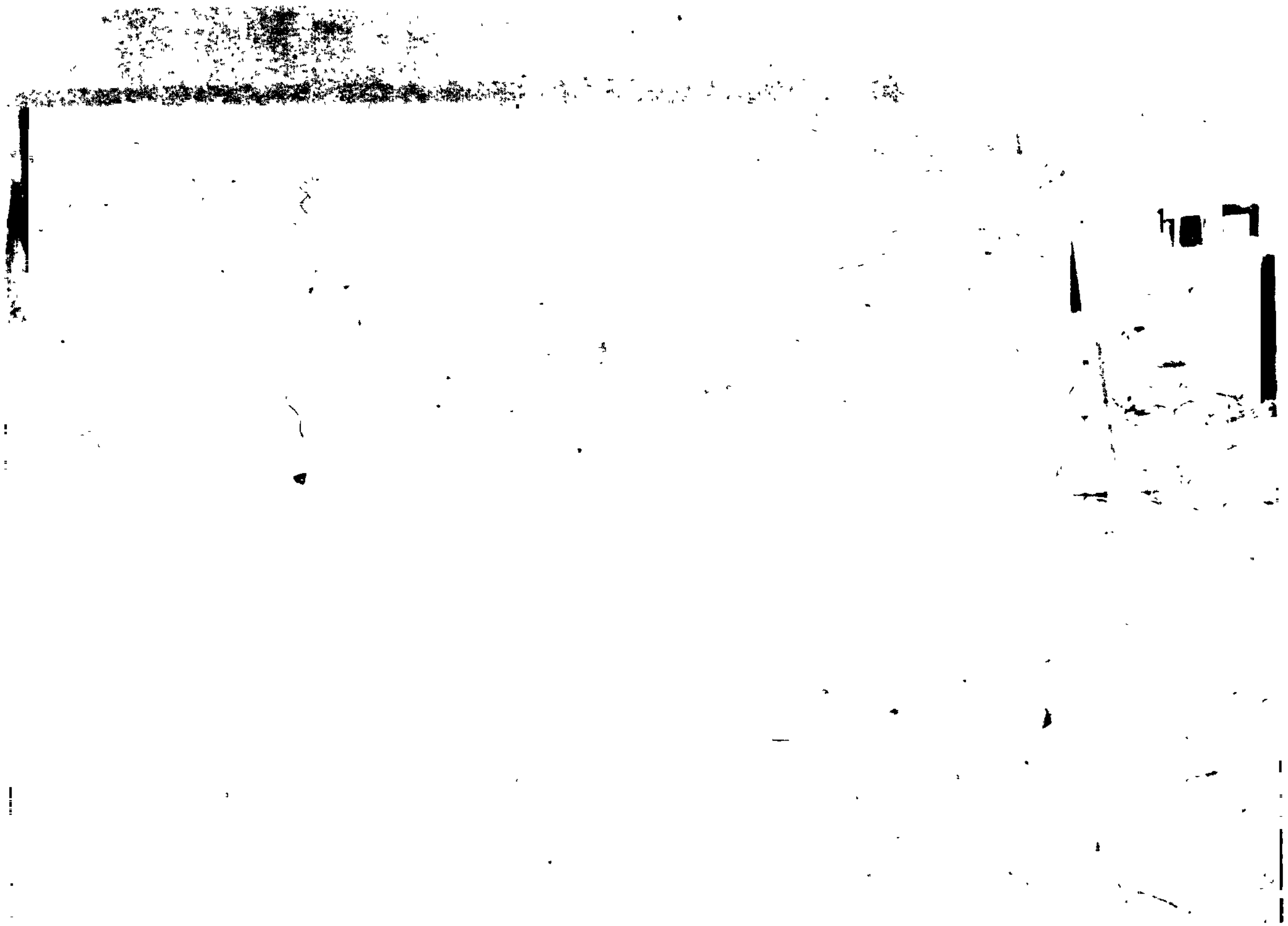


Figure 9.- Drop site in grass.

Figure 10.- Drop site in organic muck.

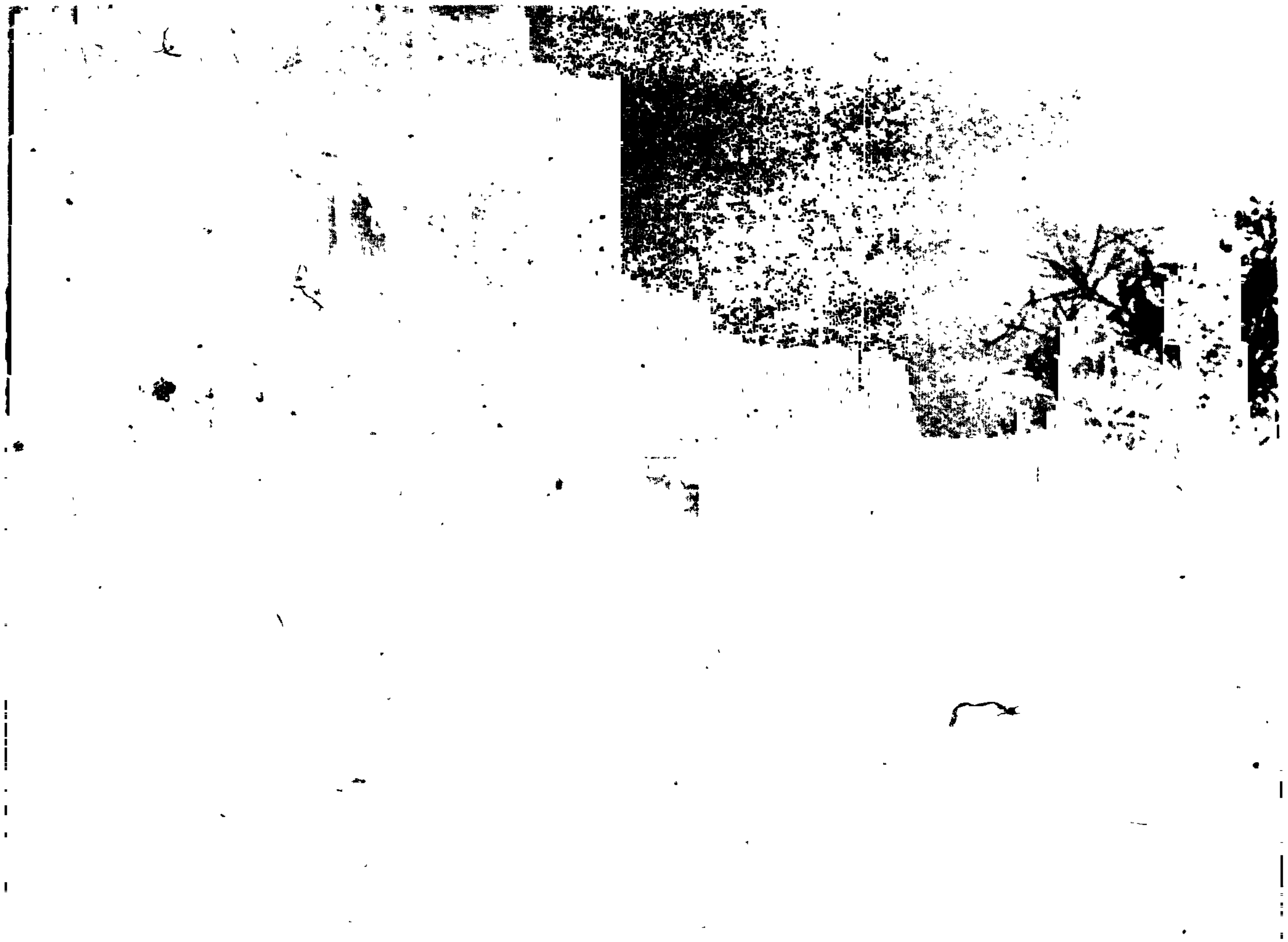


Figure 11.- Drop site in water.

APPENDIX

TEST DATA

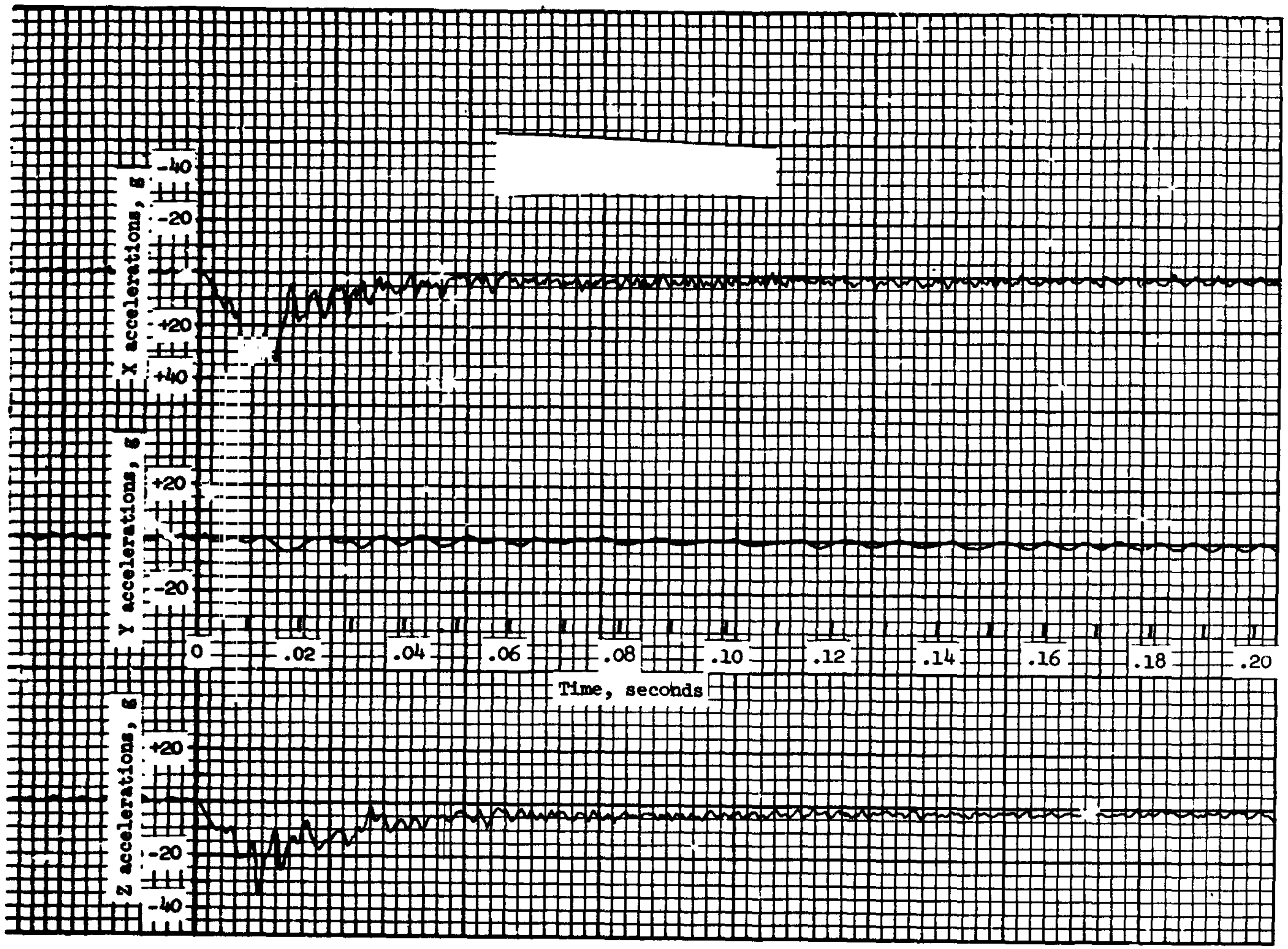


Figure A-1.- Test accelerations at MSC.

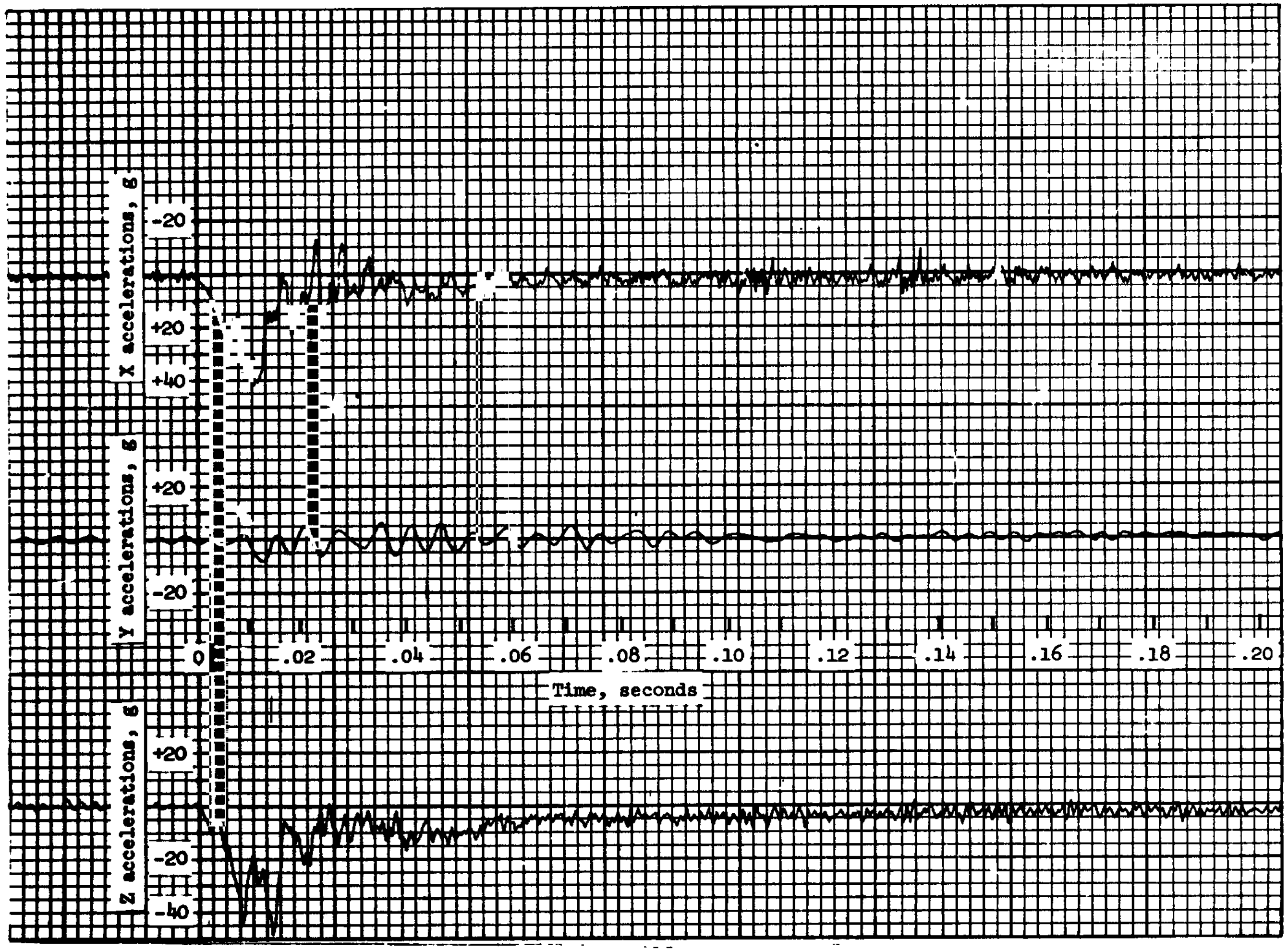


Figure A-2.- Test 1 accelerations at KSC.

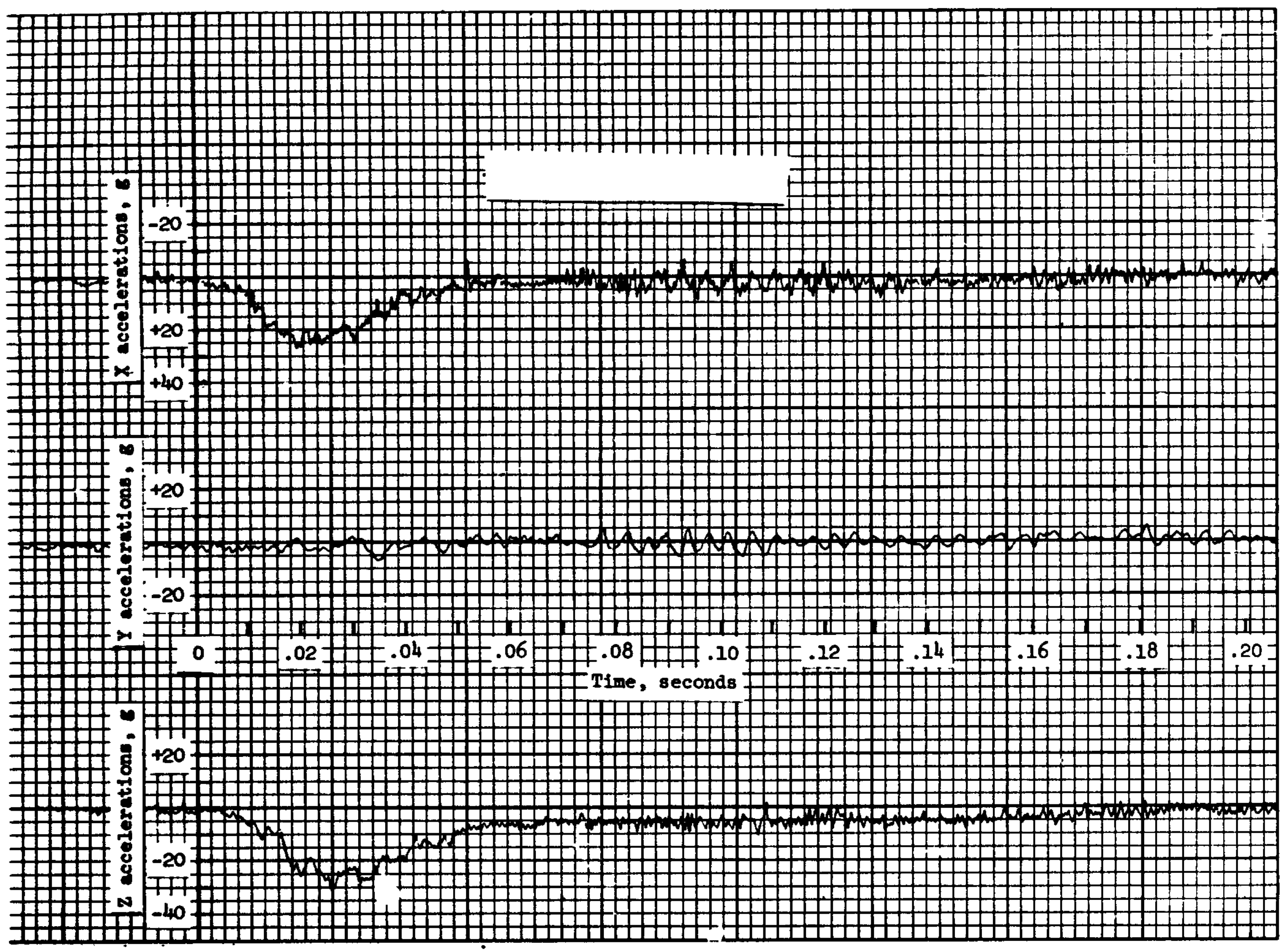


Figure A-3.- KSC test 2 accelerations.

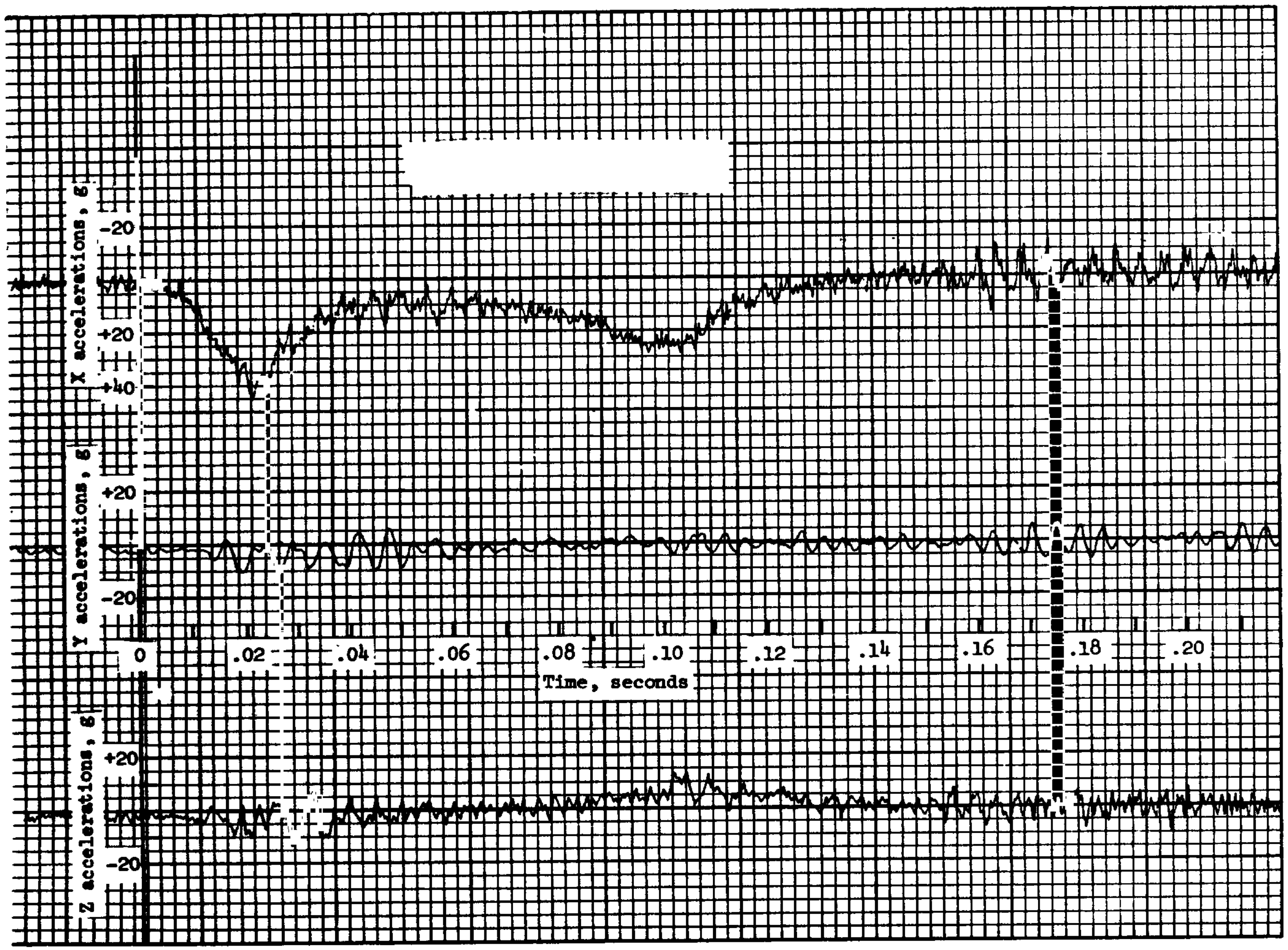


Figure A-4.- KSC test 3 accelerations.

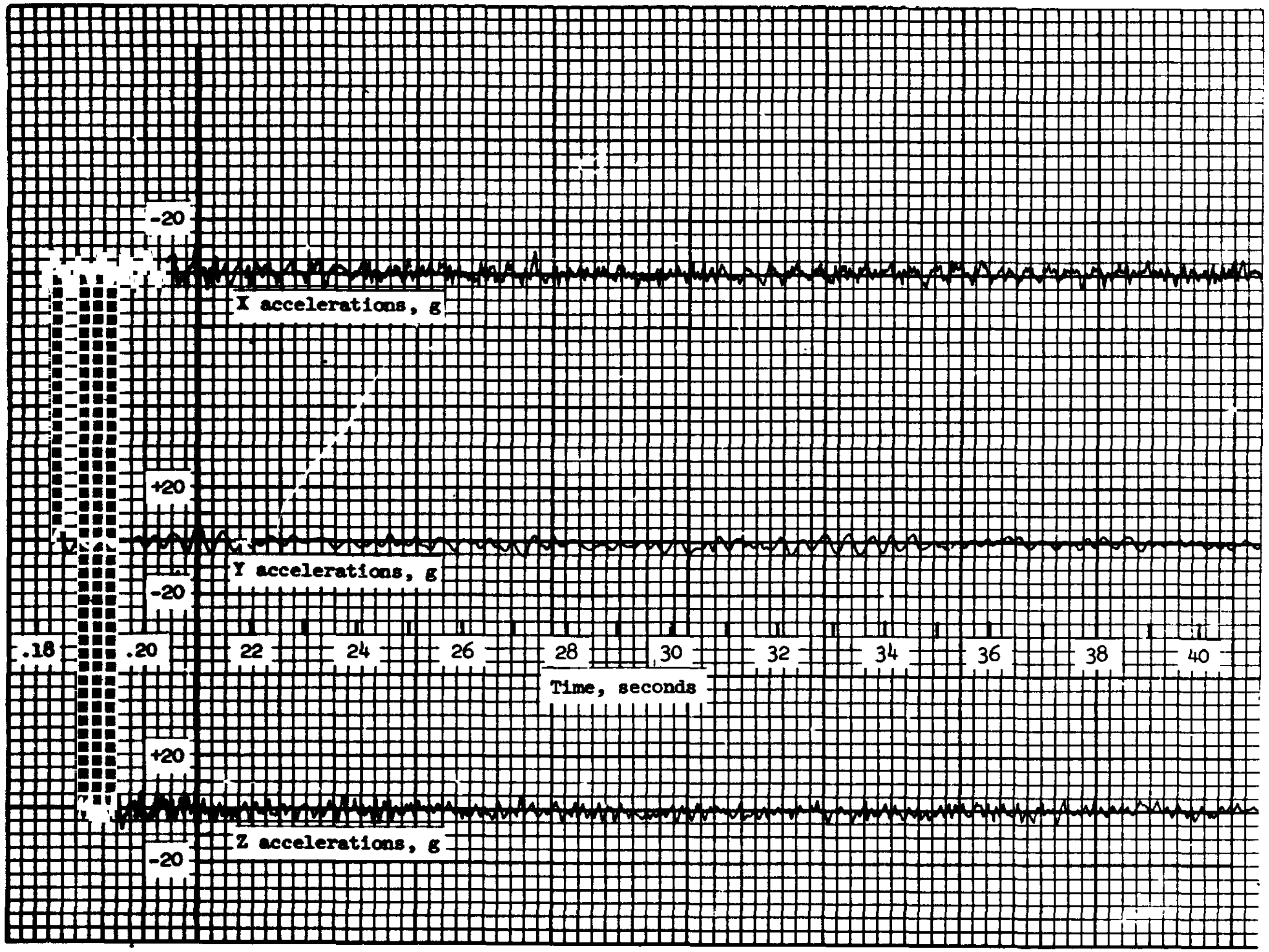


Figure A-4.- Concluded.

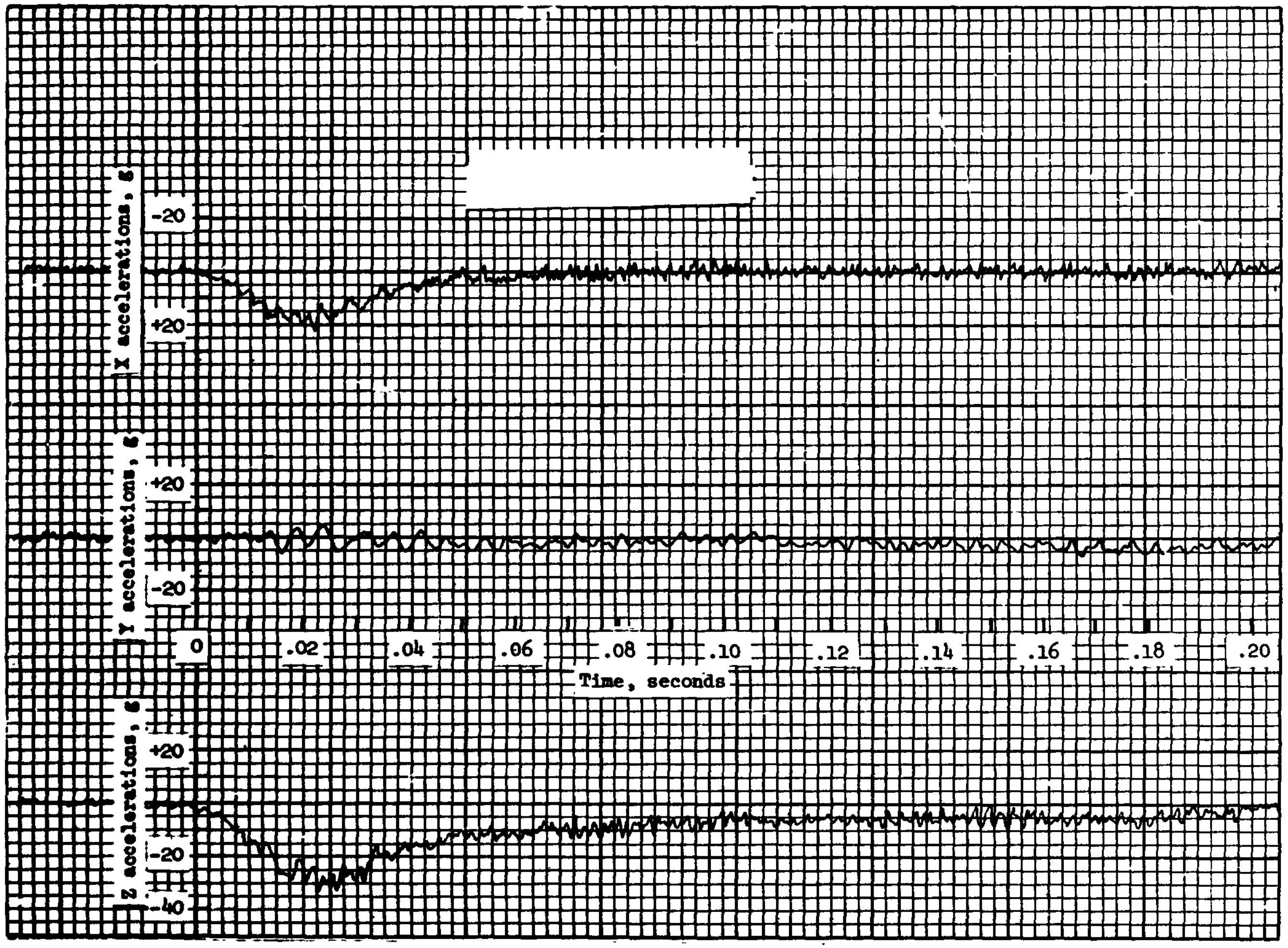


Figure A-5.- KSC test 4 accelerations.

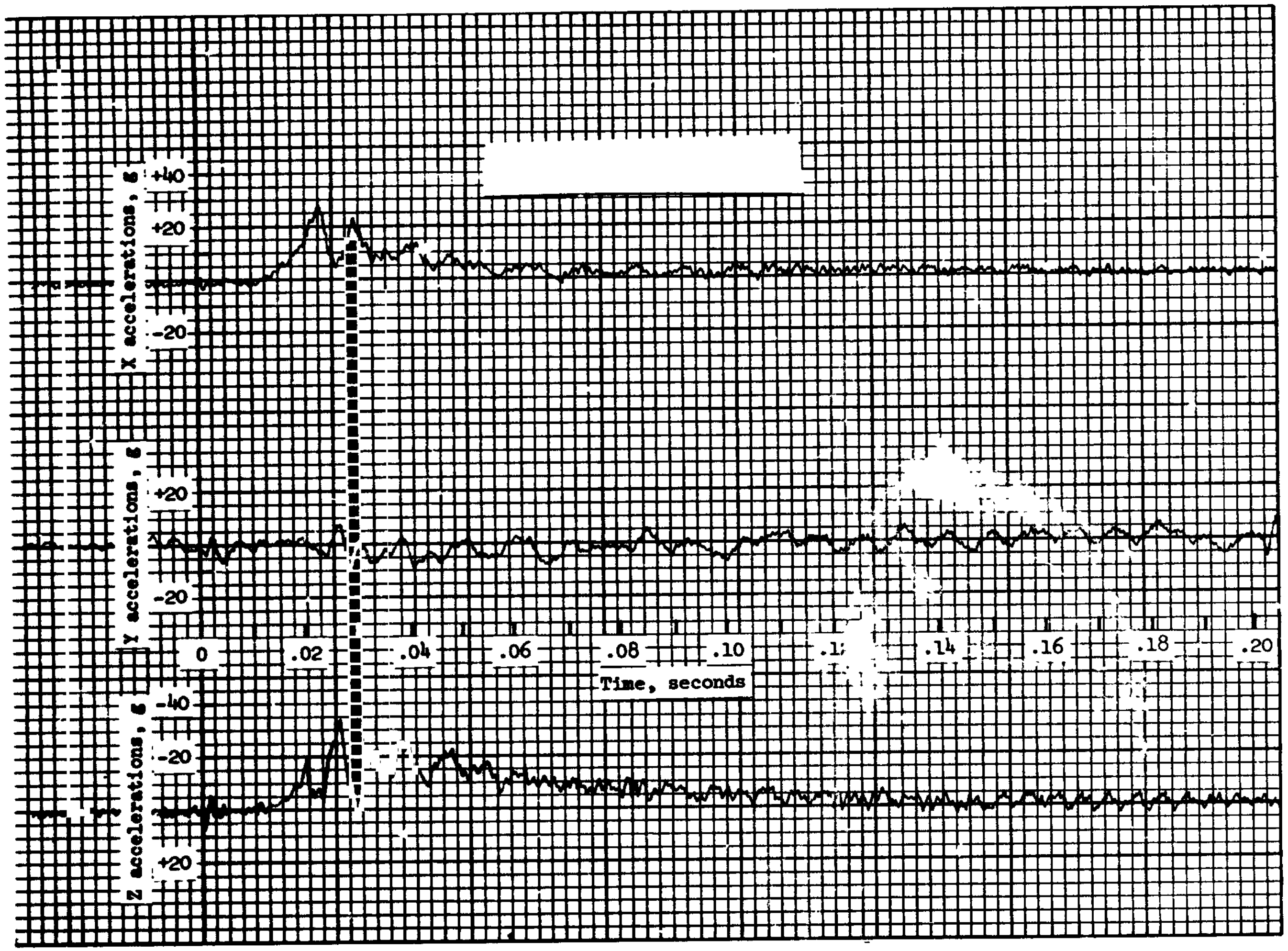


Figure A-6.- KSC test 5 accelerations.

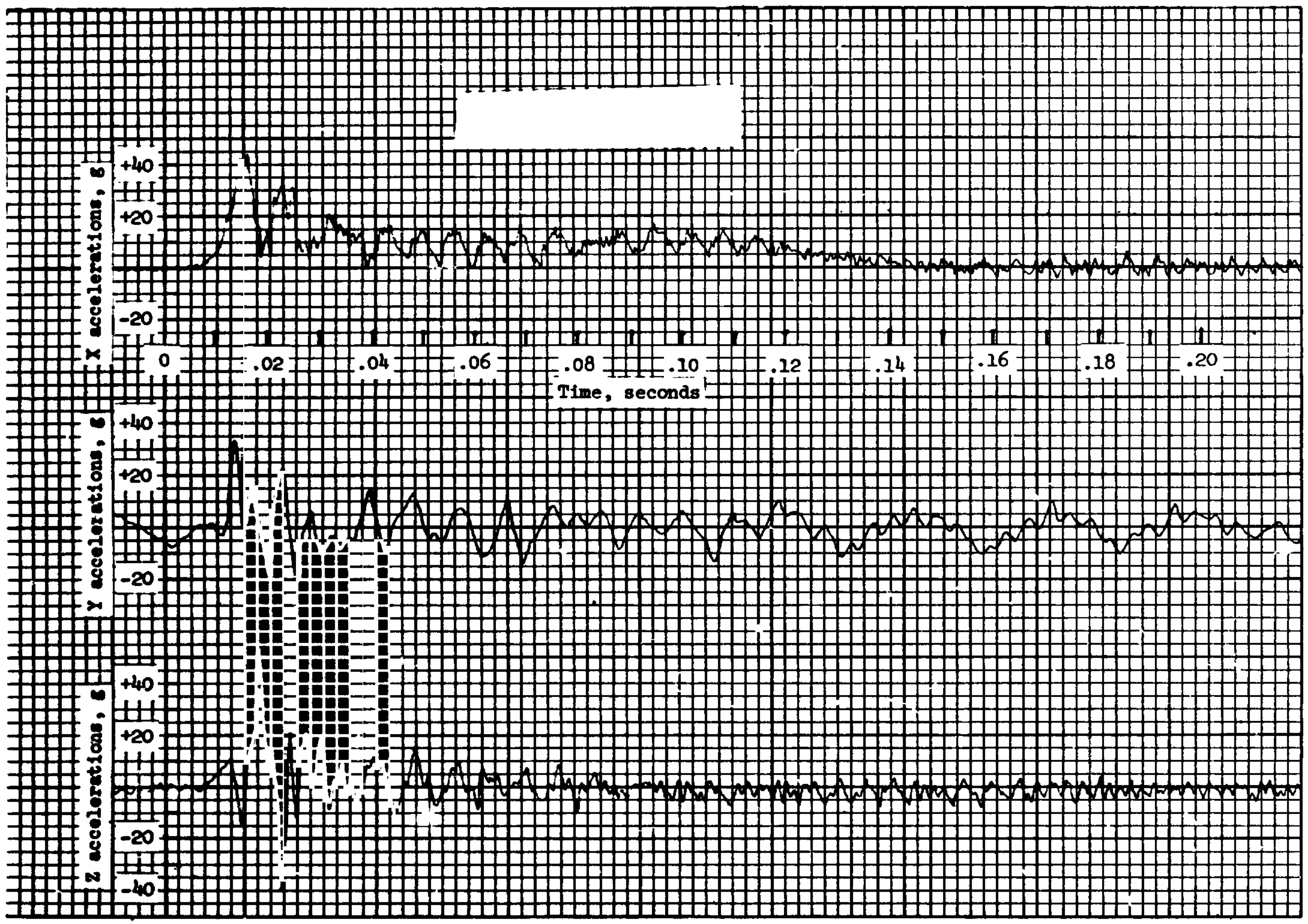


Figure A-7.- KSC test 6 accelerations.

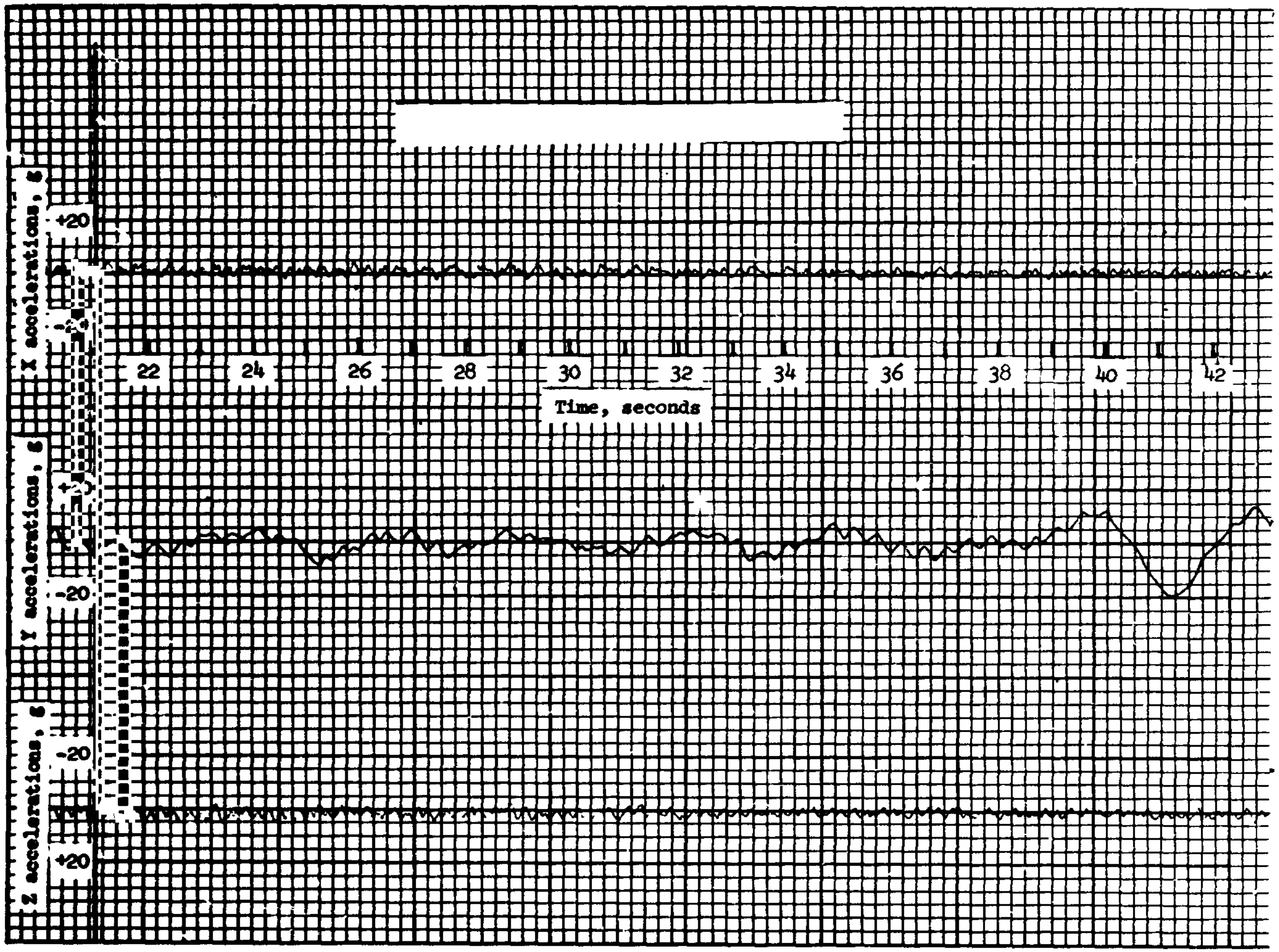


Figure A-7.- Concluded.

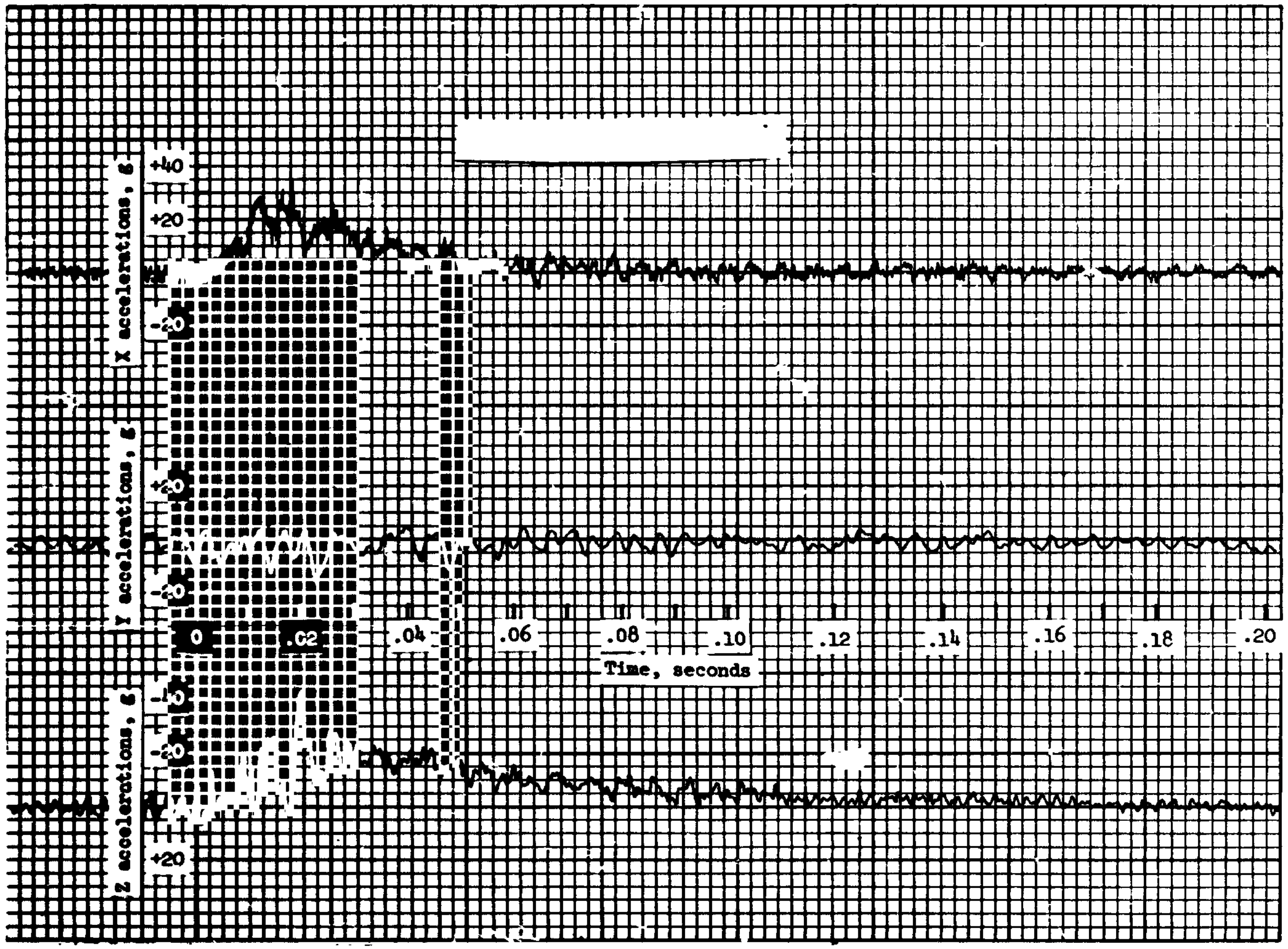


Figure A-8.- KSC test 7 accelerations.

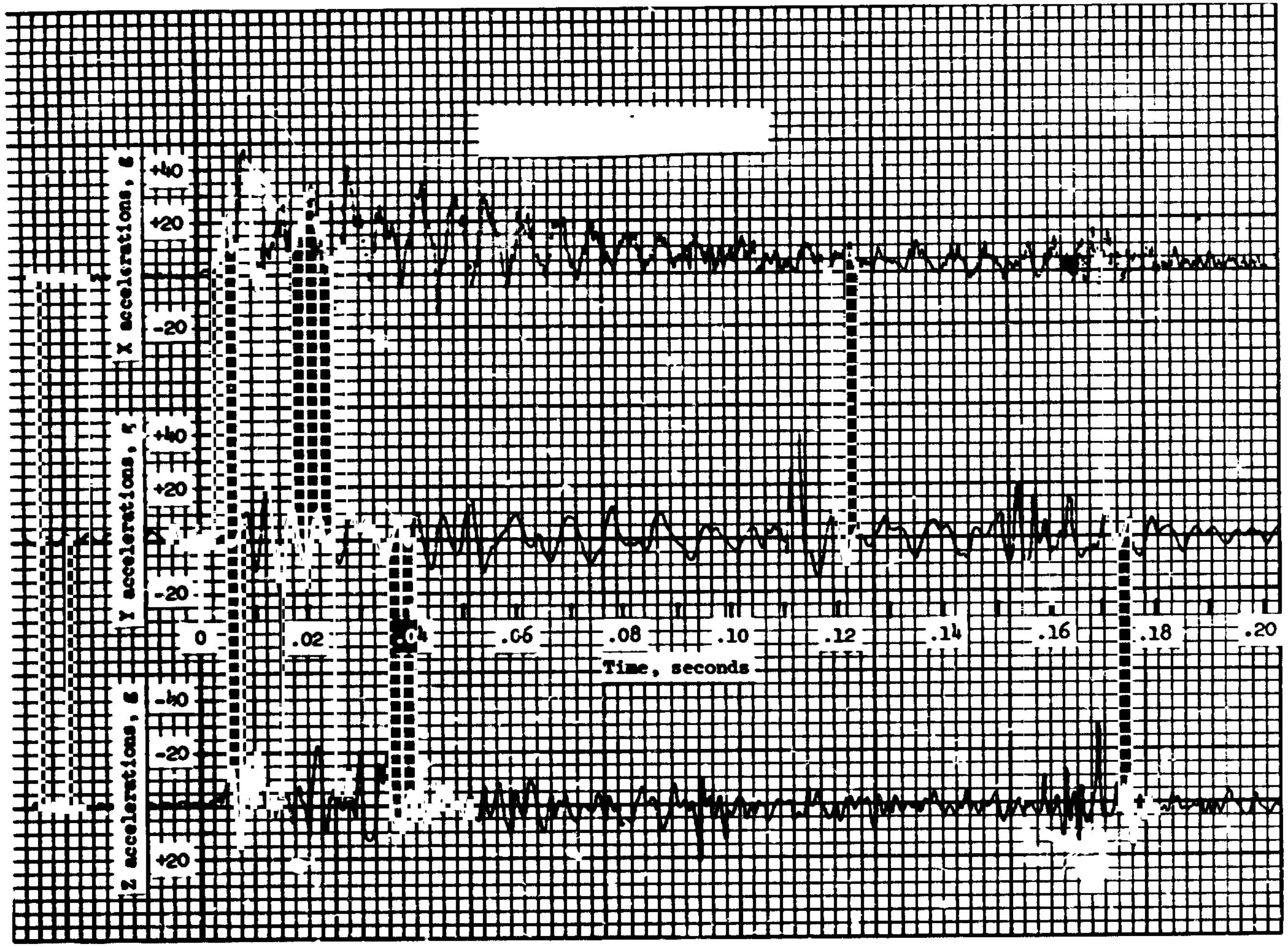


Figure A-9.- KSC test 8 accelerations.

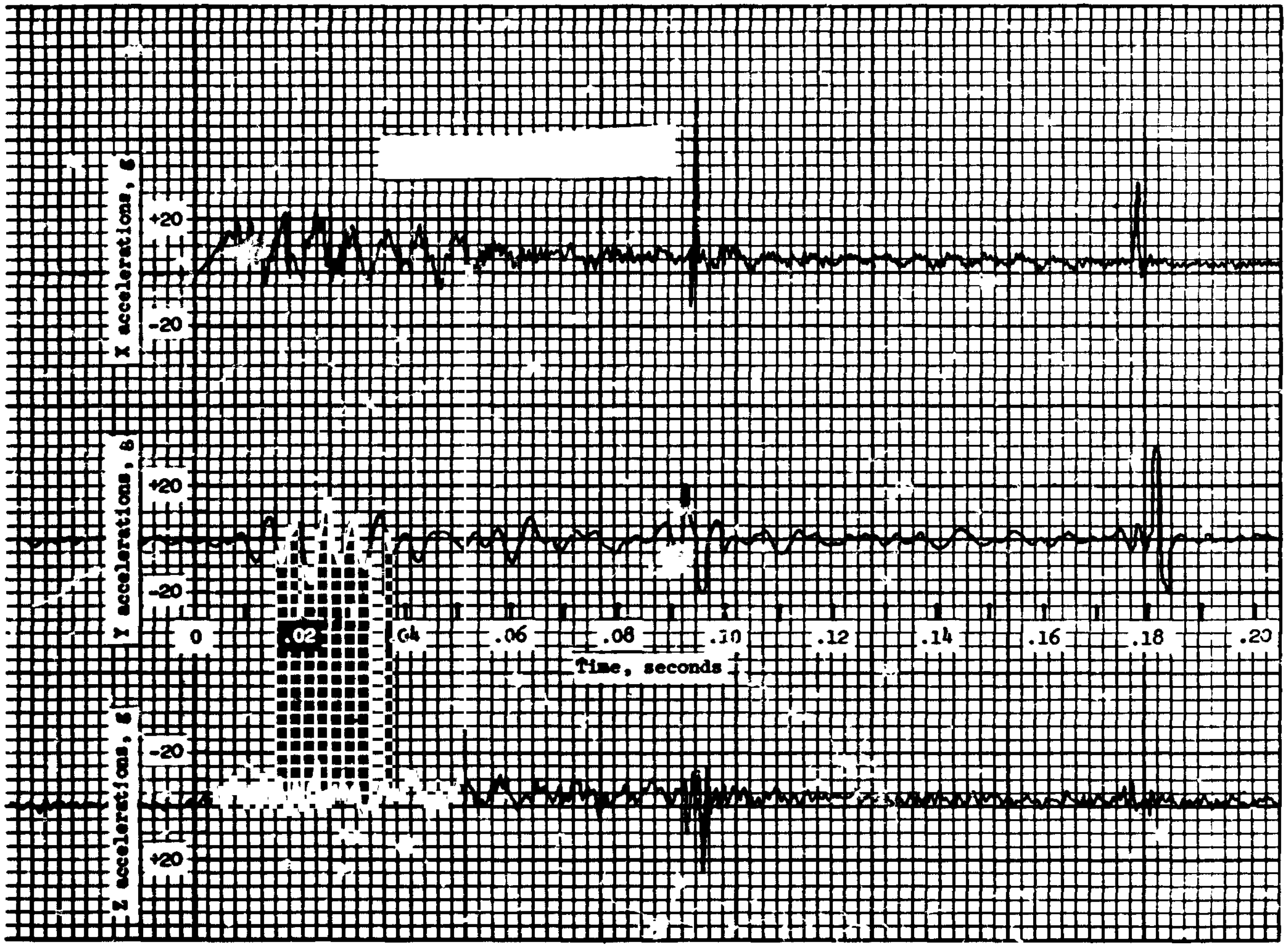


Figure A-10.- ESC test 9 accelerations.

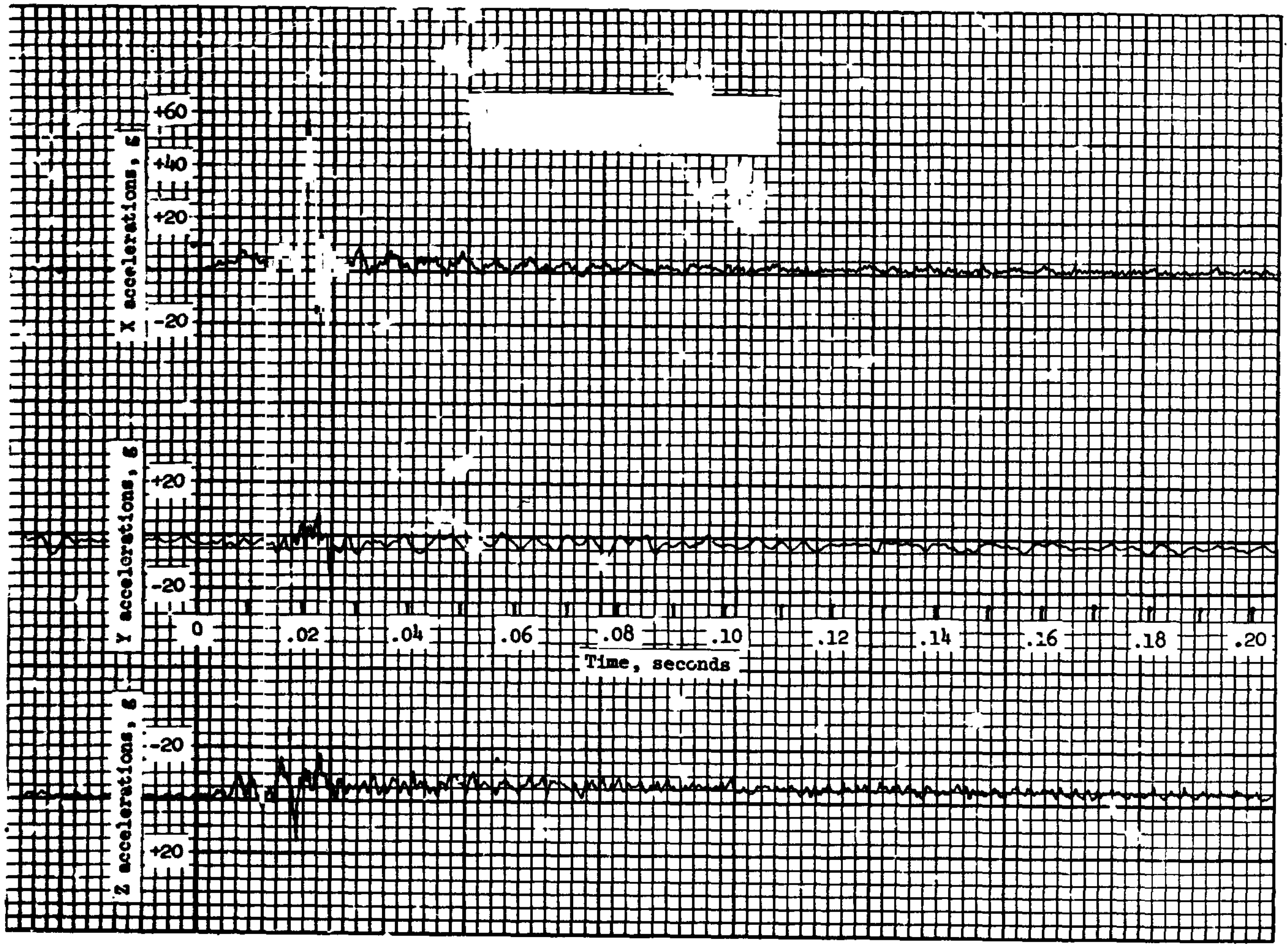


Figure A-11.- KSC test 10 accelerations.

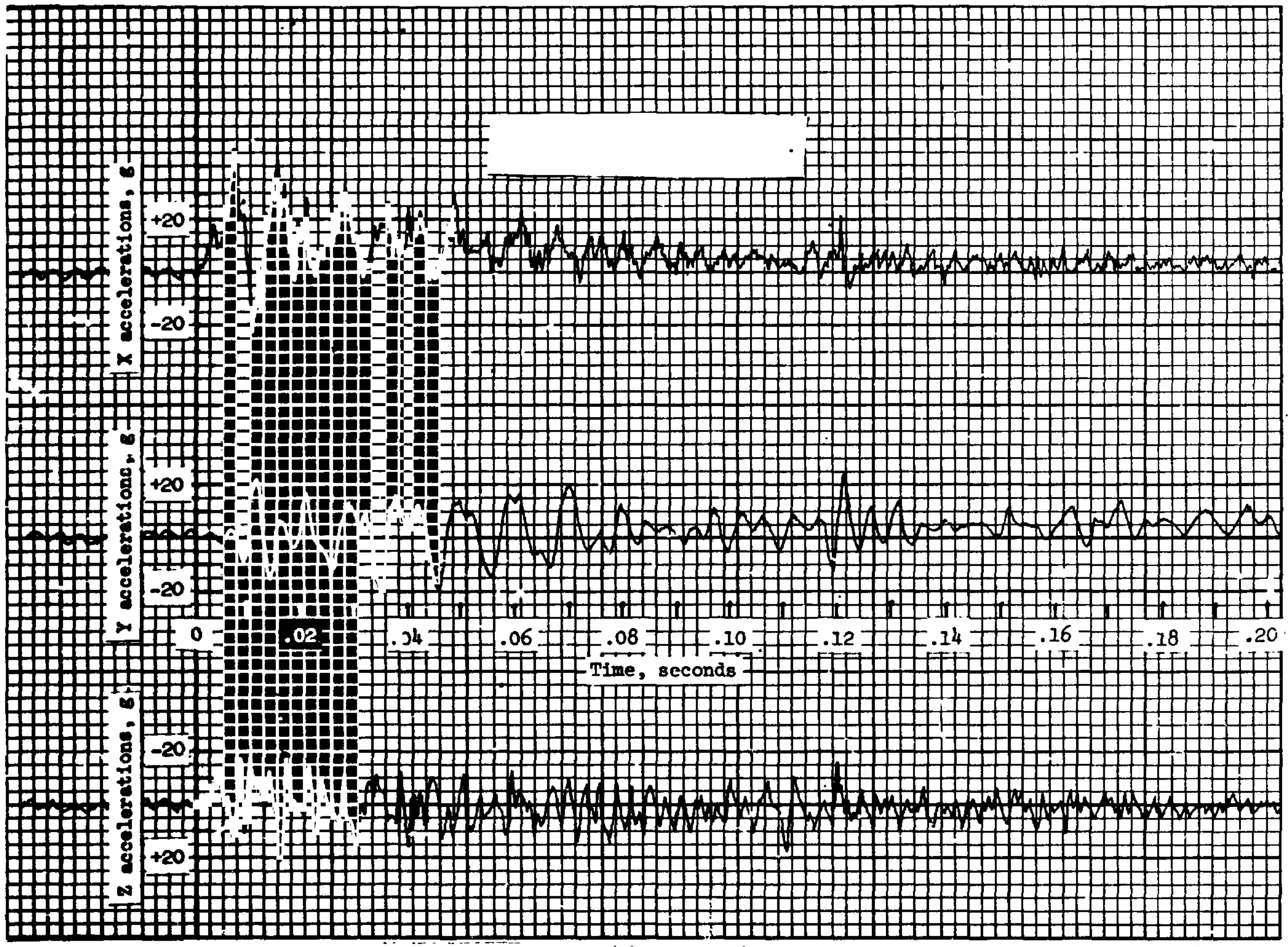


Figure A-12.- KSC test 11 accelerations.

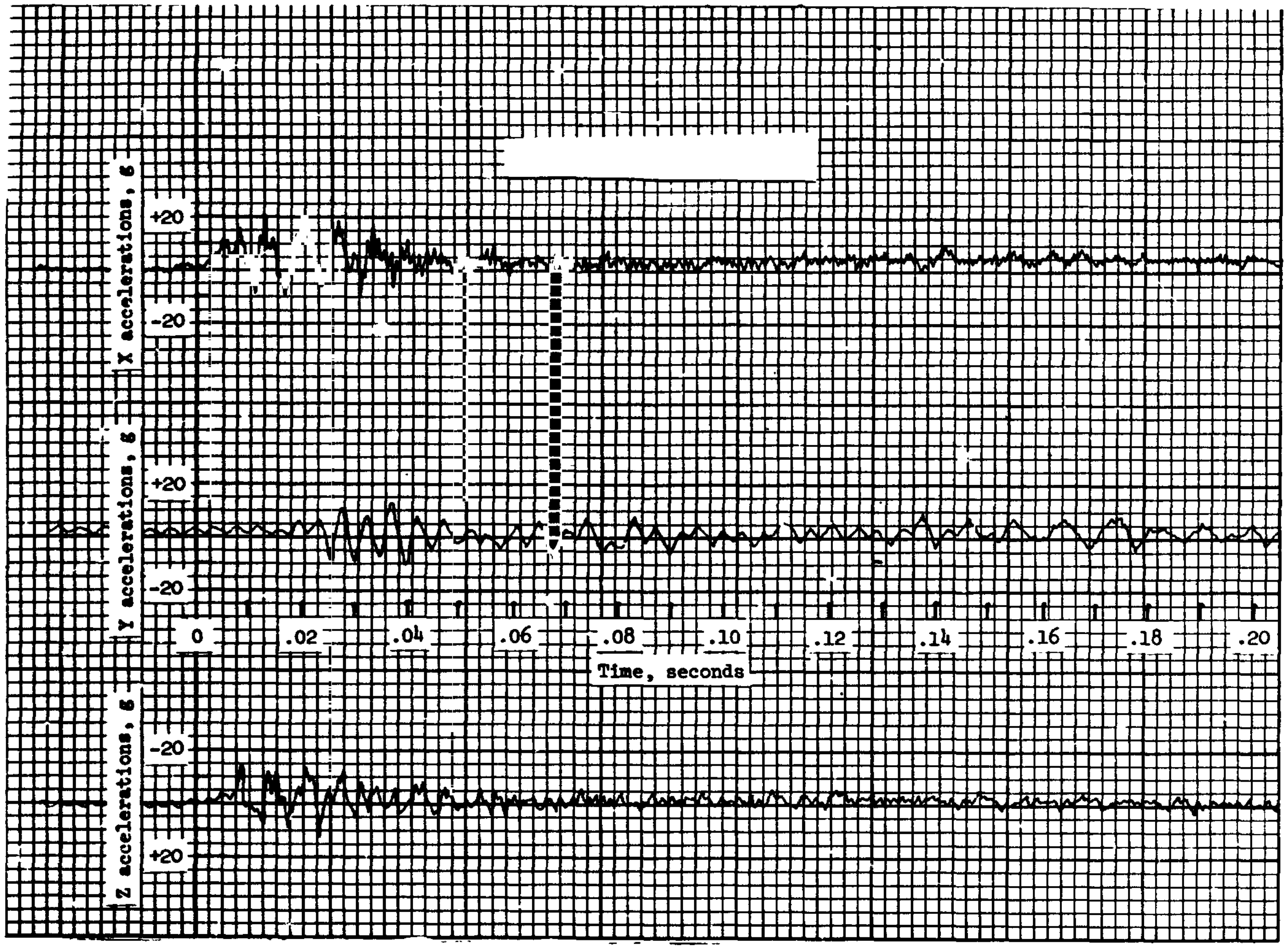


Figure A-13.- KSC test 12 accele ations.

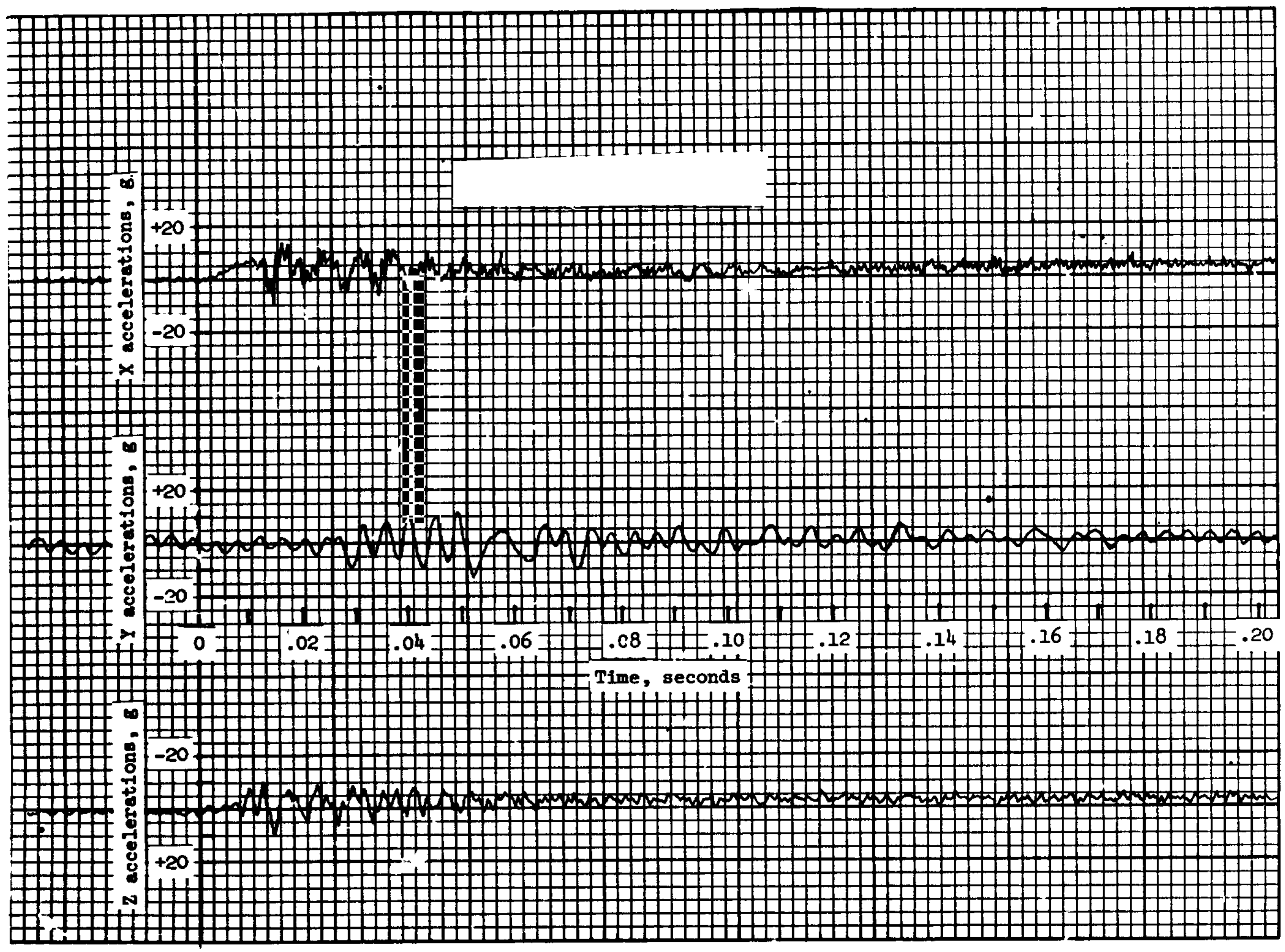


Figure A-14.- KSC test 13 accelerations.